KERNFORSCHUNGSANLAGE JÜLICH GmbH
OAK RIDGE NATIONAL LABORATORY

HET/JUPITER PROJECT ASSESSMENT REPORT

by

B.J. Baxter, F.E. Harrington (Oak Ridge National Laboratory)

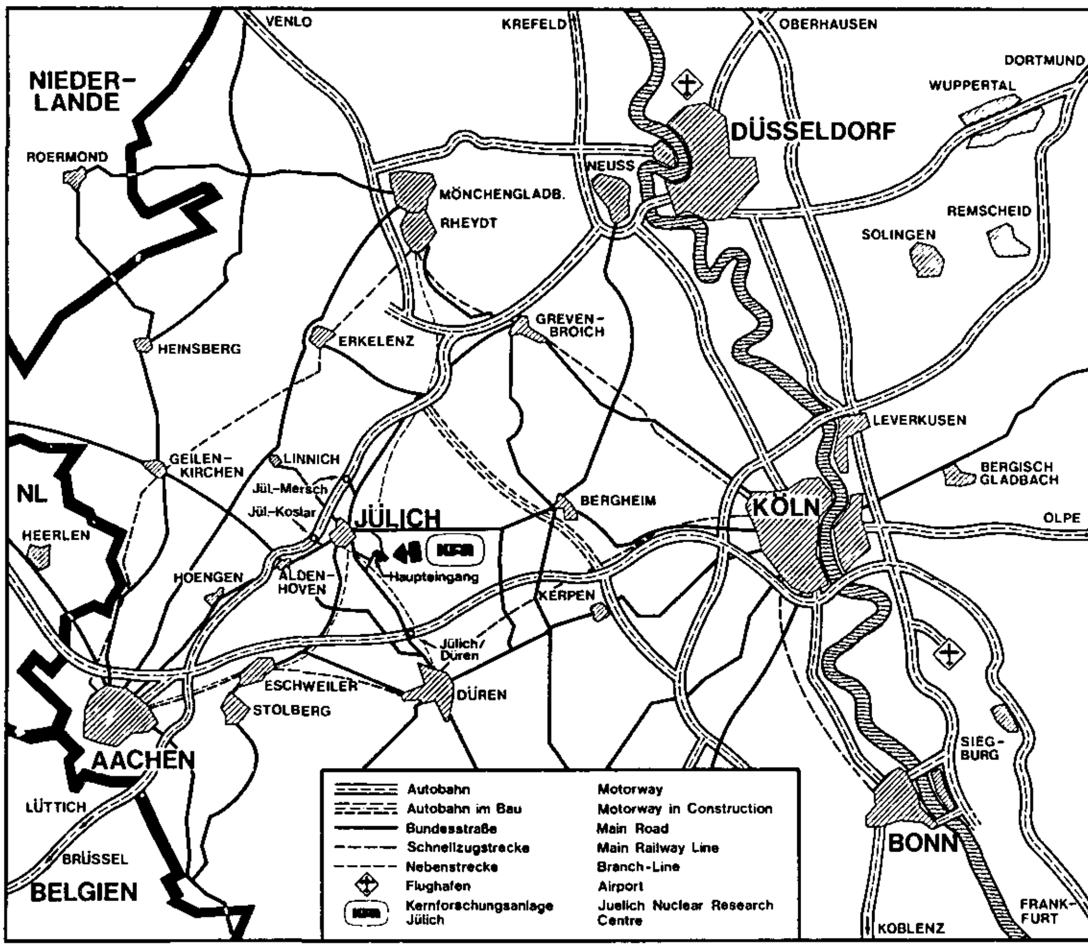
G.G. Kaiser, J. Wolf (Kernforschungsanlage Jülich GmbH)

Prepared under the Umbrella Agreement
for Cooperation in Gas-Cooled Reactor
Development between the United States
and the Federal Republic of Germany.

Research sponsored by the Nuclear Power Division,
U.S. Department of Energy under contract
W-7405-eng-26 with the Union Carbide Corporation
and the Bundesministerium für Forschung und
Technologie of the Federal Republic of Germany

Jül - Spez - 54
May 1979
ISSN p 343-7639

ORNL/NFW - 79/27



Als Manuskript gedruckt

Spezielle Berichte der Kernforschungsanlage Jülich, Jül - Spez - 54 – ORNL - 79/27

Zu beziehen durch: ZENTRALBIBLIOTHEK der Kernforschungsanlage Jülich GmbH
Postfach 1913 · D-5170 Jülich (Bundesrepublik Deutschland)
Telefon: 02461/61-0 · Telex: 833556 kfa d

HET/JUPITER
PROJECT ASSESSMENT REPORT

by

B.J. Baxter, F.E. Harrington (Oak Ridge National Laboratory)

G.G. Kaiser, J. Wolf (Kernforschungsanlage Jülich GmbH)

Prepared under the Umbrella Agreement for Cooperation in Gas-Cooled Reactor Development between the United States and the Federal Republic of Germany.

Research sponsored by the Nuclear Power Division, U.S. Department of Energy under contract W-7405-eng-26 with the Union Carbide Corporation and the Bundesministerium für Forschung und Technologie of the Federal Republic of Germany

An Assessment of the U.S. Hot Engineering Test (HET)* and FRG Jülich Pilot Plant Thorium Element Reprocessing (JUPITER)

by

B. J. Baxter
Project Leader, HET

F. E. Harrington
Project Engineer, HET

G. G. Kaiser
Project Leader, JUPITER

J. Wolf
Project Engineer, JUPITER

*Research sponsored by the Nuclear Power Division, U.S. Department of Energy under contract W-7405-eng-26 with the Union Carbide Corporation.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

HET/JUPITER PROJECT
ASSESSMENT REPORT

May 1979

B. J. Baxter G. C. Kaiser
F. E. Harrington J. Wolf

ABSTRACT

This report is an assessment of the United States' Hot Engineering Test (HET) and the Federal Republic of Germany's Jülich Pilot Plant Thorium Element Reprocessing (JUPITER) Projects. The assessment was conducted with a view to developing mutually supportive roles in the achievement of hot engineering test objectives. Conclusions of the assessment are positive and identify several technical areas with potential for US/FRG cooperation.

Recommendations presented in this report support a cost-effective US/FRG program to jointly develop high temperature gas-cooled reactor fuel recycle technology.

1. SUMMARY

This report presents an assessment of the U. S. recycle development program's Hot Engineering Test (HET) Project and FRG program's JUPITER Project. The assessment was conducted under the auspices of the US/FRG Program for Collaboration on Gas-Cooled Reactor Development and directed toward the definition of a plan for technical information exchange and reduction of resource commitments otherwise needed for the respective projects.

The methodology used in this assessment was devised to (1) provide a comparative analysis of key underlying characteristics and principles of the HET and JUPITER projects and (2) influence future decisions regarding US/FRG cooperation on hot engineering tests and related work.

The assessment centered on the following five process areas of HTGR fuel recycle:

1. fuel element size reduction,
2. fuel element burning,
3. dissolution and feed adjustment,
4. solvent extraction, and
5. product (uranium) handling.

Overall objectives of HET and JUPITER have been recognized in the context of their programmatic origins and further refined to specific technical issues. Other differences such as nuclear fuels used as process input and fundamental flowsheet differences are also discussed.

The conclusions of this assessment are (1) that differences in HET and JUPITER facility/equipment designs do not prevent the exchange of useful technical data and (2) an efficient strategy to cooperatively develop HTGR fuel recycle technology requires maximum utilization of JUPITER data and supplemental data from U. S. hot laboratory and cold engineering scale work.

2. INTRODUCTION

The United States and the Federal Republic of Germany (FRG) have organized national programs to develop and demonstrate HTGR fuel recycle technology. These programs are designed to (1) provide support for the market introduction of HTGRs, and (2) progressively evolve the technology through laboratory, engineering, and prototype phases. The engineering phase of development is particularly important to the respective programs because of the need to extend the operability of recycle processes, proven feasible in cold or nonradioactive bench-top experimentation, to the more relevant conditions involving radioactivity. Part of engineering scale development is called "hot engineering" and is recognized by the U.S. and FRG programs as separately identifiable projects designed to demonstrate specific fuel recycle processes. The U.S. program element is identified as the Hot Engineering Test (HET) Project. The corresponding FRG program element is called the Jülich Pilot Plant for Thorium Element Reprocessing (JUPITER).

The HET and JUPITER hot engineering tests are an integral part of U.S. and FRG HTGR fuel recycle development programs, and are designed to significantly reduce uncertainties associated with process scale factors and process performance in the presence of intense radioactivity. Both projects are designed to demonstrate HTGR reprocessing in the presence of radioactivity associated with ^{232}U daughter products and fission products present in irradiated graphite reactor fuels.

The US/FRG agreement on collaboration in GCR development has as a principal element the assessment of the respective hot engineering fuel recycle projects — HET and JUPITER.

The assessment authorized under this agreement is formally identified as Project Work Statement (PWS-R1). The initial U.S. proposal for assessment procedures and general format remained valid during the course of work. The proposal recommended two work sessions and a final report.

The purpose of the Work Session I was to permit the respective US/FRG Project Assessment Team members a reciprocal opportunity to present the scope, objectives, and schedule of their Project and its relationship to higher programmatic and national objectives.

The objectives of Work Session I included (1) identification of HET and JUPITER Project objectives, (2) description of technical areas with corresponding objectives, (3) establishing an information base for detailed assessment of each technical area, and (4) recommend potential areas for US/FRG collaboration on HET and JUPITER Projects.

Work Session I identified the following areas to have potential for US/FRG collaboration:

- fuel element size-reduction,
- fuel element burning,
- feed adjustment and dissolution,
- solvent extraction, and
- uranium product handling.

The objectives of Work Session I were partially achieved in August 1978. Technical descriptions and a supporting information base was established for the first two systems identified above.

The purpose of Work Session II was to extend the information base to include the remaining process systems identified above and establish a format for the final assessment report. The specific objectives of Work Session II included (1) development of technical narratives describing each area of potential technical collaboration, (2) establishment of a format for the final assessment report, and (3) development of an action plan (schedules and responsibilities) for completion of the assessment report. These objectives were accomplished in March 1979.

The overall methodology to the HET/JUPITER Assessment involved five steps; these are described as follows.

Step 1 - identification of U.S. and FRG national objectives initially supporting the HET projects. Successive clarification and refinement of these objectives through the program-project-facility-system level was jointly established by U.S. and FRG participants to the assessment.
An objectives network was developed for HET and JUPITER showing the connective relationship of each level and the point at which the two projects converged on common objectives.

Step 2 - The HET and JUPITER flowsheets were reduced to generalized block flow diagrams. Each diagram identified specific process systems as the subject of further work. Auxiliary equipment and services were also identified but were excluded from further consideration. These respective block flow diagrams were the basis of selection for the five process systems previously identified.

Step 3 - Each process system identified for HET and JUPITER was next described by a system technical summary. The summaries identified (1) operational, development, and facility requirements, (2) system makeup or principal configuration (i.e., system, subsystem, component), and (3) detailed technical issues associated with a particular requirement or configuration item.

Step 4 - Corresponding HET and JUPITER system summaries were compared and evaluated on the basis of (1) compatibility of overall design requirements, (2) design solutions to these requirements, and (3) ability of JUPITER systems to resolve outstanding technical issues of HET systems.

Step 5 - development of conclusions and recommendations that could lead to mutually supportive roles in a cost-effective international effort to develop HTGR fuel recycle technology.

The balance of this report is concerned with specific aspects of the assessment and the presentation of results.

3. HET and JUPITER PROJECT OBJECTIVES

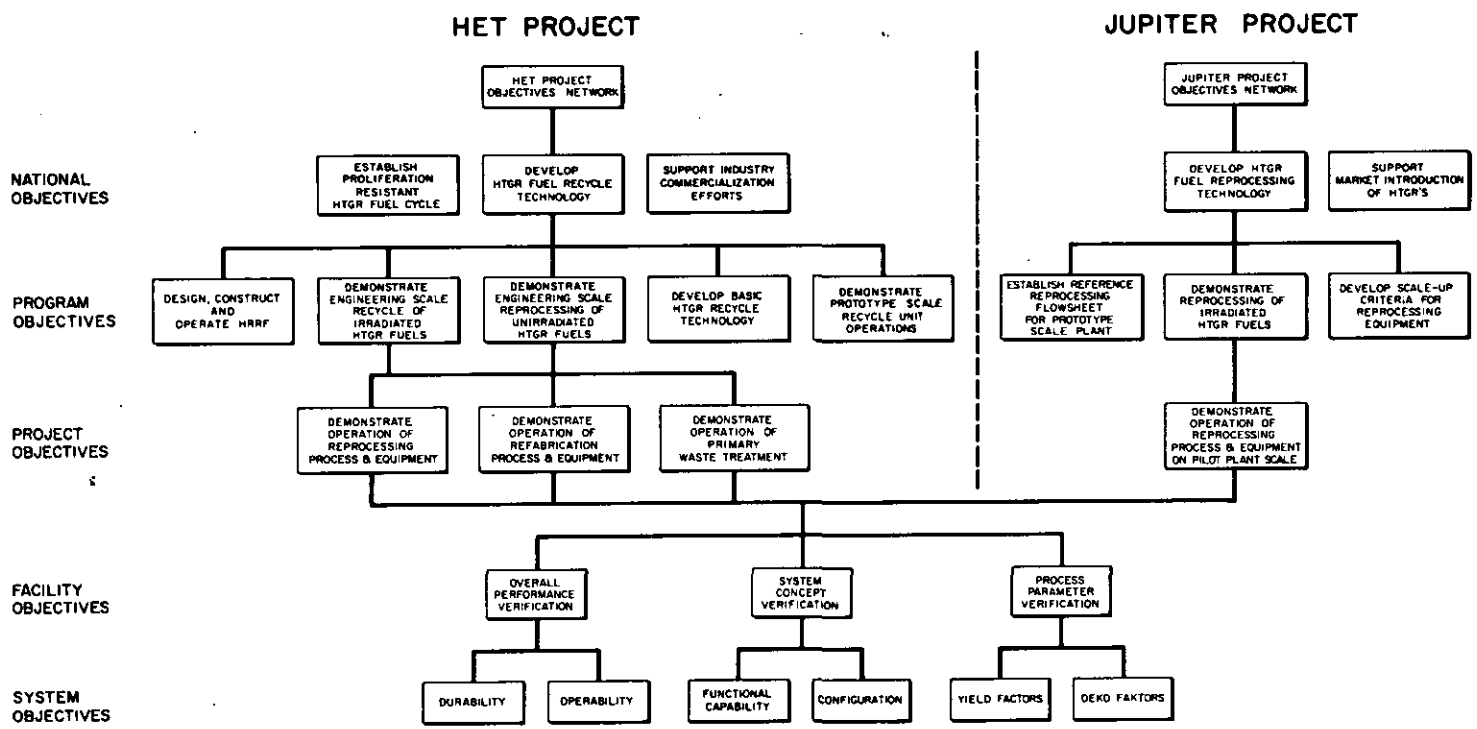
Figure 3.1 traces technical objectives of the U.S. and FRG recycle development programs from a national level to a project system level. It shows (1) how work in each program separately relates to its own national objectives and (2) where the work converges to objectives of common US/FRG interest.

For example, the U.S. national objective to develop HTGR fuel recycle technology is supported by five programmatic objectives. Of these five objectives, only one is relevant to the HET Project, that is, demonstrate engineering scale recycle of irradiated fuel. Three supporting objectives are shown to be relevant to the HET Project. The HET Project supports the U.S. HTGR Fuel Recycle Program objective to recycle irradiated fuel by demonstrating the operation of process equipment for reprocessing, refabrication, and primary waste treatment of irradiated HTGR fuels. The connective lines shown in Fig 3.1 show how HET objectives relate to the broader program and national objectives.

The FRG national objective is also to develop HTGR fuel reprocessing and fuel refabrication technology. Toward this end, the German HBK Project (counterpart to U.S. HTGR Fuel Recycle Development Program) is established to develop and demonstrate HTGR fuel cycle technology. The JUPITER Project supports the HBK Project objective by demonstrating the operation of process equipment on a pilot-plant scale for the reprocessing of irradiated HTGR fuels. This is shown in Fig. 3.1.

The U.S. and FRG work to support their respective national program and project objectives for HTGR fuel recycle and reprocessing technologies converge at the level of facility objectives. Both countries want to verify the system concepts, process parameters, and overall performance of their respective technologies through operation and evaluation of the HET and JUPITER facilities. The system

ORNL-DWG 79-13371



objectives which provide this verification, as given in Fig. 3.1, lead directly, therefore, to specific technical issues of common interest. The rest of this report identifies these issues and examines the scope of both the HET and JUPITER Projects for potential areas of fruitful exchange of information.

4. HET AND JUPITER PROJECT SCHEDULES

The planned phases of the HET and JUPITER Projects are identified with calendar time in Table 4.1. The calendar date entries are generalized to enable comparisons of early start and late finish limits on US/FRG collaboration and data exchange.

5. HET AND JUPITER FLOWSHEET REVIEW AND COMPARISON

The HET and JUPITER flowsheets are given in Figs. 5.1 and 5.2, respectively. The key elements (unit operations) of each flowsheet are summarized in Table 5.1.

Differences between the HET and JUPITER flowsheets result primarily from differences in the fuels processed. Fuel differences are described in Section 6.

Size reduction of the HET fuel (segmented Fort St Vrain fuel elements) is accomplished with an overhead eccentric jaw crusher, an oversize monitoring and recycle system, and a double-roll crusher. The pebble-bed high-temperature reactor (AVR) fuel balls, on the other hand, are reduced in size with a swinging-arm hammer mill.

Both projects use a graphite burner to remove matrix graphite and carbon coating material from the crushed fuel. The HET Project, however, requires a secondary burner to remove carbon-coating material inside an unburnable silicon-carbide layer on the TRISO-coated Fort St Vrain (FSV) fuel particles. The JUPITER Project does not require a secondary burner, since the AVR fuel has no unburnable particle coatings.

The HET Project uses an air-classification system to separate fissile (^{235}U) and fertile (^{232}Th) heavy-metal carbide particles which

Table 4.1. HET and JUPITER Project Schedules[a]

Phase	Design	Construction	Installation	Shakedown Testing	Cold Checkout	Hot Checkout and Operation	Decontamination and Decommission
JUPITER							
Head-End	1972–1973	1973–1975	1976–1978	1978–1979	1980–1982	1985–1988	1989
Process	1973–1975	1975–1979	1980–1982	1983	1983–1984	1985–1988	1989
HET	1980–1982	1982–1984	1984–1986	1986	1986–1987	1988–1990	1991

[a]Calendar time.

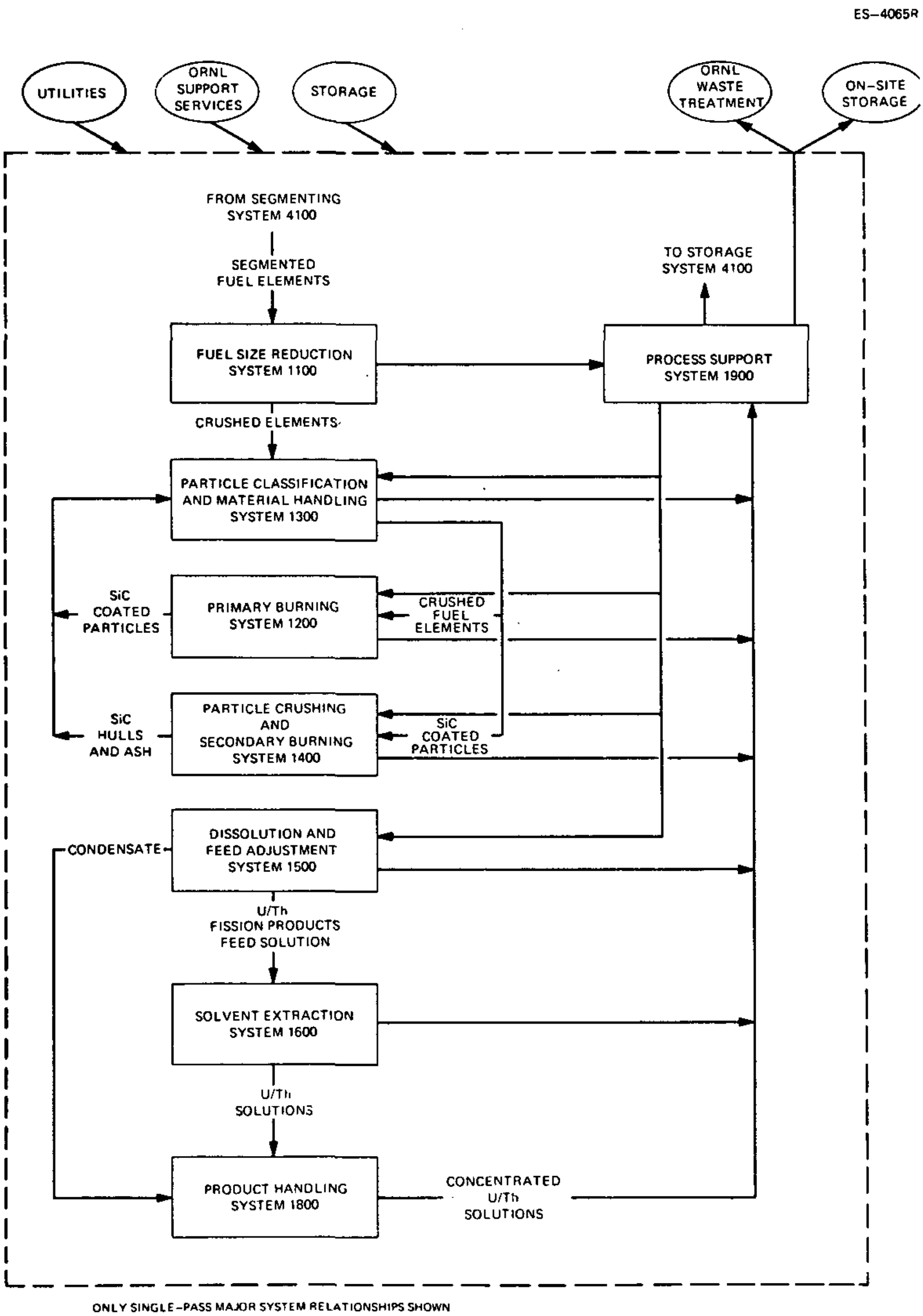


Fig. 5.1. Generalized HET Fuel Reprocessing Block Diagram.

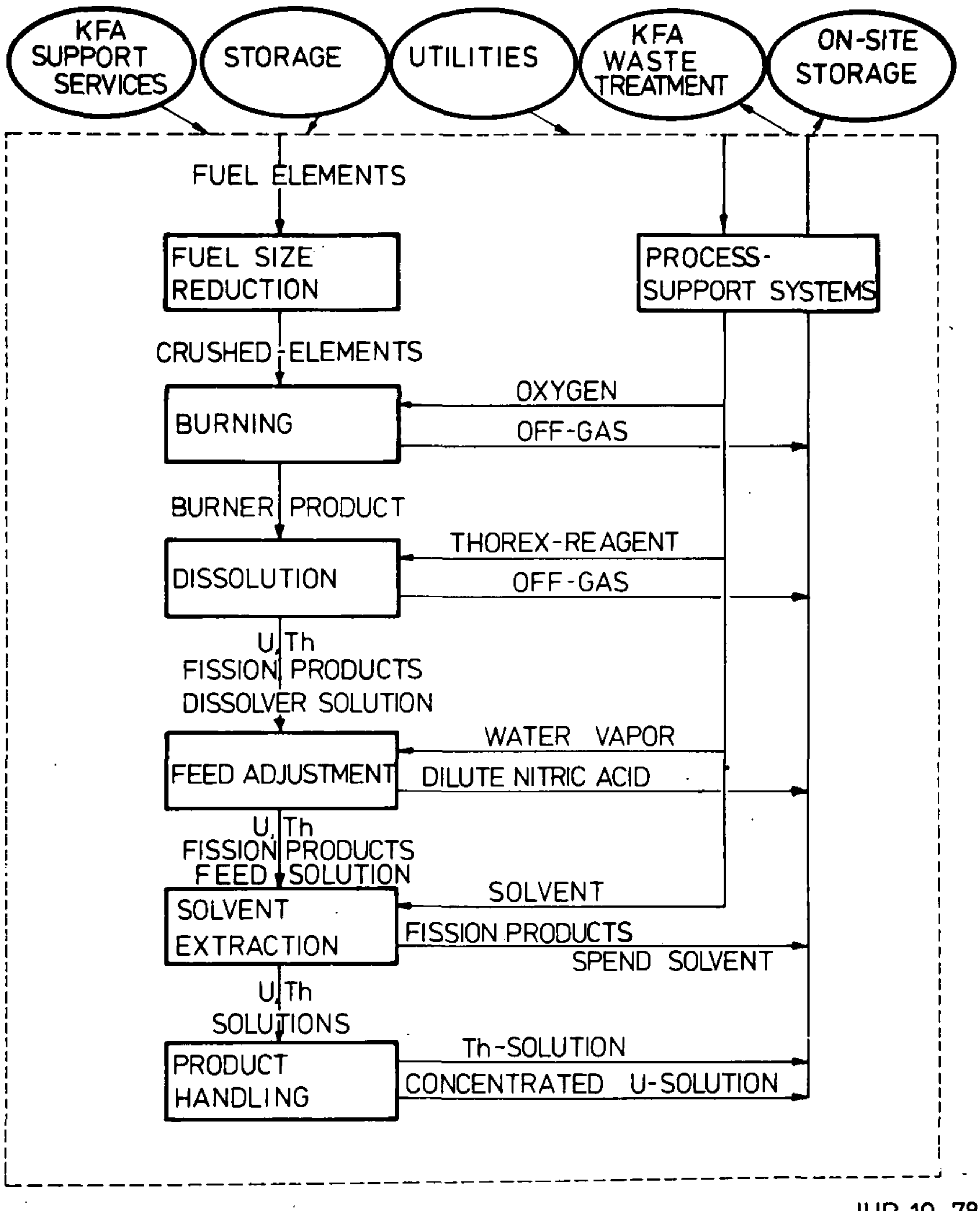


Fig. 5.2. Generalized JUPITER Fuel Reprocessing Block Diagram.

Table 5.1. HET/JUPITER flowsheet comparison

Unit operation	HET	JUPITER
Size reduction	X[a]	X
Graphite burns	X	X
Particle classification	X	
Particle crushing/secondary burns	X	
Dissolution and feed adjustment	X	X
Solvent extraction	X	X
Product (uranium) handling	X	X

[a]X = Present in Flowsheet.

exist as a mixture in the FSV fuel. Since the AVR fuel uses a single mixed (U/Th)-oxide particle, no such separation is required in JUPITER.

Particle crushing is required by the HET Project to crack the silicon-carbide coating on the TRISO-coated FSV fuel particles, exposing the inner carbon coatings to secondary burning. The JUPITER Project does not require this function since the AVR fuel has no comparable inert particle coating.

Both dissolution/feed adjustment and solvent extraction are used in both flowsheets, although HET uses pulse columns and JUPITER uses mixer-settlers. The HET dissolution/feed adjustment requires leaching and then separation and isolation the silicon-carbide hulls. This step is not required in JUPITER.

6. HET AND JUPITER PROJECT FUEL REVIEW AND COMPARISON

The HET and JUPITER facilities are designed to reprocess spent Fort St Vrain (FSV) fuel and pebble-bed high-temperature reactor (AVR) fuel, respectively.

The FSV fuel is a two-particle system, with uranium carbide (UC_2) as the fissile fuel and thorium carbide (ThC_2) as the fertile fuel. The spent FSV fuel contains both recoverable ^{235}U and ^{232}Th and, in addition, bred ^{233}U, a fissile isotope of uranium. The fissile and fertile FSV fuel particles are TRISO-coated, having three carbon layers and one layer of silicon carbide for retention of fission products.

The pebble-bed high-temperature reactor (AVR) fuel is a single-particle system, with a mixed (U/Th)-oxide fuel. The spent AVR fuel also contains recoverable heavy-metal isotopes of uranium and thorium. The fuel particles are contained within a graphite matrix.

Additional characteristics of the two fuels are given in Table 6.1.

7. SUMMARY OF HET AND JUPITER PROCESS SYSTEM

Appendices A and B provide technical summaries of the respective HET and JUPITER Project process systems. Each summary identifies (1) operational, facility, and development requirements, (2) system configuration and component identification, and (3) specific technical issues.

It is the purpose of this section to consolidate these summaries by identifying the scope of issues associated with the development of each process system and briefly describe the HET and JUPITER design solutions for each system.

An assessment of technical issues and design solutions is first presented as findings. These findings are further condensed to conclusions regarding the likely substitutability of HET and JUPITER systems, information, or data.

7.1 FUEL ELEMENT SIZE REDUCTION

Appendix A1 and B1 are technical summaries of the HET and JUPITER Project size-reduction system, respectively. This section consolidates these summaries.

Table 6.1. FSV (HET) and AVR (JUPITER) fuel characteristics

	HET	JUPITER	
FUEL CONFIGURATION	prismatic (hexagonal) blocks	spherical balls	
SIZE	79cm high × 35.6cm	6cm diameter	
WEIGHT	125 kg	200 g[a]	200 g[b]
graphite	103.3 kg	194 g	189 g
heavy-metal	21.7 kg	6 g	11 g
BURN-UP (FIMA)		10–15%	5–10%
fertile	∿7%		
fissile	∿15%		
FUEL			
<u>Fissile</u>			
Composition	Th-UC_2 (Th/U = 4,25:1)	$(Th,U)O_2$ (Th/U = 5:1)	$(Th,U)O_2$ (Th/U = 10:1)
Coating	TRISO/TRISO	HTI/BISO	HTI/BISO
Kernel Dia (min-max)	100–275	354–425	354–425
Particle Dia (min-max)	300–500	630–850	630–850
<u>Fertile</u>			
Composition	ThC_2		
Coating	TRISO		
Kernel Dia (min-max)	300–500		
Particle Dia (min-max)	500–800		
SEPARABILITY	yes	no	
GRAPHITE	H327	NUKEM A3	
REACTOR DISCHARGE	180 days	≥150 days	

[a]Fuel with AVR fuel specification.

[b]Fuel with THTR fuel specification.

7.1.1 Scope of Technical Issues

The principal requirement of HET and JUPITER fuel element size-reduction systems is to produce feed material which is suitable for fluidized-bed combustion.

Although the respective projects propose two different design solutions to satisfy this requirement, the scope of technical issues can be summarized in the following points:

- Crushing behavior and
- Remote operability of size-reduction systems.

The scope of interest in crushing behavior as a technical issue centers on differences in irradiated and unirradiated fuel elements. Irradiation is expected to produce changes in the size distribution of the crushed product and amount of breakage of fuel particles as a result of crushing action. Changes in the size reduction arise primarily from the strengthening of graphite during irradiation and the attendant influence on fracture mechanisms during crushing. Fuel particle breakage during crushing is increased with irradiated fuel. The increase is largely the result of thermal and irradiation induced brittle behavior and lower bulk physical strength of particles.

The scope of concern with the remote operability of HET and JUPITER size-reduction systems focuses on specific design features. Remote features of the HET and JUPITER size-reduction system satisfy operational objectives and provide flexibility under highly specific contingency conditions. The HET proposes a jaw/roll crusher whereas JUPITER utilizes a hammer-mill for the size reduction of spent fuel elements. The basic nature of the respective design solutions makes difficult a direct comparison of their remote operability. However, comparative conclusions might ultimately be drawn regarding inherent advantages and disadvantages of each system. Such conclusions would be useful to the design of advanced systems.

7.1.2 Design Solutions

7.1.2.1 HET Size-Reduction System

The HET size-reduction system utilizes an overhead eccentric jaw crusher for the primary reduction of 79 cm long, triangular segments cut from spent Fort St Vrain fuel elements. The segments are reduced to be nominally ≤3/4 in. (≤2 cm) ring size material. The crushed product is screened and oversize material recycled through the jaw crusher. The jaw crusher product is to be further reduced to less than ≤3/16 in. (≤0.5 cm) ring size material. Because the HET size-reduction system is conceptual and not tested, actual size-distribution and particle breakage data cannot be measured. However, the jaw/screen/roll configuration is similar to the cold-engineering size-reduction system currently under development at General Atomic Company. The cold-engineering system accepts a whole FSV fuel element and produces a size-distribution characterized by a mean size of 1200 μm (36.8 wt. %) and a maximum particle size of 3/16 in. (0.5 cm). Particle breakage in this system for TRISO/BISO carbide fuel is shown in Table 7.1.

The jaw/screen/roll assembly is vertically configured to utilize gravity flow for intra-equipment material flow.

The system is dust tight and utilizes 1 ft^3/min (28.3 liters/min) of CO_2 gas purge for dust control and removal. The purge gas is filtered and discharged into the facility off-gas system.

The size-reduction system is sized for a throughput equal to or greater than one Fort St Vrain fuel element per hour.

7.1.2.2 JUPITER Size-Reduction System

The JUPITER size-reduction system utilizes a swinging-arm hammermill for the single stage reduction of spent AVR fuels. The AVR fuel is 6 cm in diameter and approximately 14 elements per hour are fed to the hammermill. The resulting size distribution is characterized by a mean particle size of 400 μm (36.8 wt. %) maximum size of ∿1/16 in. (1.5 mm). Unirradiated fuel particle breakage has been measured in the range of 14 wt. %.

Table 7.1 Cold Engineering Scale Fuel Particle Breakage Data

Fuel Element Type	PARTICLE CHARACTERISTICS		
	TYPE	SIZE RANGE (μm)	BREAKAGE w/o
FSV Std. Fuel Element	TRISO fertile	500–800	12
	TRISO fissile	300–500	1
FSV Control Rod	TRISO fertile	500–800	31
	TRISO fissile	300–500	2
LHTGR Std. Fuel Element	TRISO fissile	- - - -	2
	BISO fertile	425	1/2

The hammermill is operated at atmospheric pressure with a valve interlock to charge fuel balls into mill. The discharge section of hammermill is fitted with a variable speed screw conveyor. The conveyor is connected to the fluidized-bed burner and a slow purge of CO_2 at $\sim$2 in. (50 cm) H_2O to prevent cell air from being admitted to burner.

7.1.3 Assessment

The assessment of HET/JUPITER size-reduction systems is presented in two parts; they are, findings and conclusions. Section 7.1.3.1 gives the assessment team's findings which expand the technical issues listed in Appendix A1 and B1. Section 7.1.3.2 gives the team's conclusions concerning the scope of future cooperative work to resolve common technical issues.

7.1.3.1 Findings

A brief discussion of findings on each technical issue is provided below.

Crushing Behavior. Both HET and JUPITER Projects will determine differences in the crushing behavior of irradiated versus unirradiated fuel elements by contrasting differences in the respective size distributions. Both projects are interested in changes in the relative proportion of fines (<50 μm), the relative proportion of maximum sized particles and in the mean size of the particle size distribution. The particle size distribution produced by the JUPITER hammermill design is expected to differ from that produced by the HET jaw/roll design owing to different operational characteristics of the HET and JUPITER size-reduction systems. Direct differences in the size distributions of HET and JUPITER size-reduction system are not of themselves significant.

HET and JUPITER Projects interest in the shape of particles is limited to the large sized particles of the distribution. The HET interest centers on the tendency of H327 graphite to produce elongated particles. Although this tendency is the result of anisotropy and not irradiation effects, the observation of particle shape is of importance to the design of transport, storage, and feeder systems. JUPITER's project interest in particle shape distribution is observational as the AVR fuel utilizes near isotropic graphite.

The coefficient of friction of irradiated AVR fuel is an issue specific to the JUPITER Project. Interest in the coefficient of friction is twofold: (1) as it relates to the performance and design of the screen feeder and (2) as it relates to the motion of AVR fuel balls through a feeder pipe and entry into the hammermill.

Radiation Effects. The effects of radiation on HET and JUPITER size-reduction equipment is an important technical issue because (1) it affects the ability of the respective equipment to perform an intended function and (2) it influences the basic operability of each design solution. Radiation effects on JUPITER equipment are expected for cumulative doses of 10^8 rad. The HET equipment will experience higher doses and the effects are, therefore, anticipated to be more severe for the same exposure period. The difference is not considered major since actual exposure will be a function of actual material heels in equipment and specific fuel elements used in tests.

Dusting. The generation of dust is an indirect and unavoidable product of the size-reduction process. Control of dust in a cell is a technical issue from the standpoint of material accountability and effective control of surface contamination of nonprocess equipment. A greater degree of dust control is required in HET than JUPITER owing to a relatively greater fuel element size-reduction requirement (i.e., reduction of a 125 (kg) FSV element vs reduction of a ∿200 g AVR element). For this reason HET and JUPITER size-reduction systems have provisions for dust control by enclosure, however, only the HET system utilizes positive ventilation and dust samples for confirmation of control.

Fission Product Release. The release of volatile, semivolatile fission products and particulate release during size reduction is a consequence of fuel particle breakage. The degree of fuel particle breakage (see item f, this section) is expected to be different for the JUPITER BISO particles than for the HET TRISO particles. Release of these substances, therefore, is expected to be proportional to (1) the quantity in which they are present in the respective BISO or

TRISO particles and (2) the amount of particle breakage introduced during size reduction. Volatile releases include the noble gases such as xenon and krypton and are expected during size reduction. Semivolatile releases such as cesium, ruthenium, and molybdenum require pyrochemical conversion in the case of HET/TRISO-coated carbide fuel and high temperatures for JUPITER/BISO fuel. Semivolatile releases are not expected during size reduction. Particulate release falls in the category of dusting and is discussed under item c of this section.

Equipment Holdup. The holdup of process materials is an HET/JUPITER technical issue because (1) material accountability requirements on special nuclear materials and (2) basic fundamental process operating philosophy which requires material balances on throughput and process inventories. Differences in the degree of special nuclear material holdup can be expected in HET/JUPITER size-reduction equipment owing to differences in throughput, equipment size, and configuration. The HET size-reduction equipment is sized primarily to initially accommodate long segments of Fort St Vrain fuel elements and not to satisfy a particular throughput requirement. The system is configured to provide a two-step reduction with an intermediate scalping operation. The two steps are effected by a jaw/roll crusher sequence using process industry equipment which is designed for efficient cleanout. The JUPITER size-reduction system takes advantage of relatively small feed size (AVR fuel balls) and effects the size reduction in a single stage utilizing a hammermill.

For nearly equivalent throughput [12,000 kg (27,000 lb) for HET, approximately 11,800 kg (26,000 lb) for JUPITER] material holdup is expected to be greater in the HET system.

Fuel Particle Breakage. Fundamental differences exist in the type of fuel particles to be processed by HET/JUPITER Projects and the degree to which fuel particle breakage affects the size-reduction operation is a direct consequence. JUPITER processes BISO coated single particles $(Th,U)O_2$ and HET processes TRISO coated fertile and fissile (Th/U-4.25) fuel particles. Particle breakage has a different consequence for downstream JUPITER processes than it does for HET processes. Excessive (14 wt. %) particle breakage during JUPITER size reduction complicates the burner operation and, in particular, gives rise to excessive quantities of broken particle fragments in the burner fines. Excessive particle breakage in HET has the downstream consequence of ^{236}U crossover contamination of the fertile (bred ^{233}U) owing to the attendant inability to cleanly separate fertile/fissile streams on the basis of size and density.

Maintenance Philosophy. The HET/JUPITER maintenance philosophies are intended to accomplish specific operational objectives and largely follow the remove and replace concept. In situ maintenance requirements are minimized and restricted to those system components operating under severe service conditions. Both HET and JUPITER are pilot-plant operations having a short operating life and no particular need to advance remote maintenance technology beyond current state-of-the-art.

Time Consolidation. The consolidation of crushed fuel elements or burner feed is a practical consideration for HET and JUPITER. Once placed in a storage bunker, the void space initially present in the crushed material is unavoidably reduced with time. Consolidation of the crushed product makes difficult the controlled withdrawal or feeder operation. The crushed material can, under certain conditions involving time, form a bridge over the bunker outlet and, thereby, restrict the flow of material to the feeder device.

The JUPITER project utilizes a mechanical bridge breaker to dislodge material under these conditions. The bridge breaker is located inside the burner feed bunker and extends outside where it can be manually actuated.

The HET project utilizes pneumatic or air pads located inside the burner feed bunker and immediately adjacent to the bunker outlet. Once actuated, the pads introduce air to the packed mass of crushed material, expand the material, and initiate flow.

7.1.3.2 Conclusions

Conclusions on each technical issue is provided below. A tabular summary of these conclusions is provided in Table 7.2.

Crushing Behavior. The HET and JUPITER size-reduction systems can be expected to produce mutually exclusive crushing behavior because (1) the respective design solutions to size reduction produce inherently different products and (2) the feed materials are fundamentally different in geometry and physical properties. No quantitative and direct comparison of HET/JUPITER crushing behavior is possible.

Radiation Effects. The effects of radiation environment on HET and JUPITER size-reduction equipment is a potential area of collaboration. Because this information is largely design related, HET/JUPITER equipment items need to be reviewed to determine susceptibility to these effects. Specific recommendations should be developed regarding the measurement of life-cycle exposure and dose rate experience by impacted equipment.

Dusting. The problem of dusting, as evidenced by design, is of more concern to HET than JUPITER size-reduction equipment. For reasons cited

Table 7.2. Fuel Element Size Reduction Conclusion Summary

HET Technical Issues	Obtainable from JUPITER	Comment
1. Crushing behavior	NO	• fundamental differences in design solution • basic differences in feed material geometry • basic differences in physical properties of feed material
2. Radiation effects of equipment	YES	• data on equipment life cycle exposure and dose rate possible
3. Dusting	YES	• qualitative information possible; JUPITER design does not possess sampling capability
4. *Volatile fission* product and particulate release	YES	• *fission product release is largely a function of* particle breakage for TRISO particle systems. JUPITER BISO system can provide qualitative information for comparison with cold engineering data • *particulate release as a result of the size-* reduction process - SEE DUSTING
5. Equipment hold-up and decontamination	YES	• qualitative comparison of JUPITER data with cold engineering data is possible - HET and JUPITER have nearly equivalent throughputs
6. Particle breakage	YES	• direct substitution of JUPITER data is not possible owing to difference in fuel particle types, irradiation, and thermal histories; process design limits on particle breakage may be inferred
7. Product shape and size	NO	• see comments on "Crushing behavior"
8. Maintenace philosophy	YES	• limited data transfer is possible owing to fundamental differences in HET and JUPITER

Item 2a above, only qualitative assessments will be possible. The JUPITER equipment will require the addition of a dust sampling cpability to provide information on this technical issue.

Fission Product Release. Collaboration on this technical issue is possible. Release of volatile noble gases are expected as a result of particle breakage. Measurement of particle breakage in the respective systems and knowledge of the thermal and irradiation histories of JUPITER-BISO or HET-TRISO particles will allow comparative assessments and provide a basis for future designs. Particulate release as a result of the size-reduction process falls under the category of dusting.

Equipment Holdup. The holdup of process material in HET and JUPITER size-reduction systems depends upon (1) specific details of the respective design solutions and (2) the total throughput of each pilot plant. Although HET and JUPITER size-reduction system will experience nearly equivalent throughputs, the respective design solutions preclude a quantitative comparison or substitution of this data. A qualitative comparison of JUPITER data could be made with cold engineering data.

Fuel Particle Breakage. Collaboration on this technical issue is possible with appropriate allowances for difference in HET/JUPITER; they are (1) design solutions, (2) fuel particle type, and (3) thermal and irradiation histories of the fuel particles. Although a direct correlation or substitution of data is not possible, process design limits on particle breakage could be inferred.

Maintenance Philosophy. Collaboration on this technical issue is not possible owing to significant differences in HET/JUPITER design solutions and to a lesser extent operational objectives of the respective size-reduction systems. The operability and maintenance requirements of each system is certainly of interest because of the overall complexity of remote maintenance operations; however, mutual substitution of HET or JUPITER experience is not possible.

Time Consolidation. Collaboration on this techncal issue is possible. Time consolidation of process material (in this case crushed irradiated fuel elements) is an important operational consideration and one which directly affects the throughput of HET and JUPITER pilot plants.

7.2 FUEL ELEMENT BURNING

Appendices A2 and B2 are technical summaries of the HET and JUPITER Project burners, respectively. This section consolidates these summaries.

7.2.1 Scope of Technical Issues

The principal requirement of the HET and JUPITER burner systems is to remove matrix graphite and carbon-coating material from the fissile and fertile fuel particles after initial size reduction of the spent fuel. Although the two burner systems are designed differently and operate differently, the scope of common technical issues is summarized as follows:

- special nuclear materials (SNM) accountability control,
- irradiated particle behavior,
- burner operation and control,
- burner corrosion, and
- burner maintainability.

7.2.2 Design Solutions

7.2.2.1 HET Burner System

The HET burner system uses a vertical cylindrical vessel for fluidized-bed burning of crushed irradiated fuel elements. The vessel inside diameter is 8 in. (20 cm). The crushed feed 3/16 in. (≤0.5 cm) ring size is introduced to the burner at an average rate of approximately 278 lb (126 kg) (1 fuel element) during an 8-h period. This is equivalent to a burn rate of approximately 26 lb/h (0.0033 kg/s). The burner is operated at approximately 1652°F (900°C) during equilibrium combustion periods. The operating pressure at the gas distributor is typically 6–10 psig (14–17 kPa).

The HET burner uses gaseous carbon dioxide (CO_2) and oxygen (O_2) to fluidize the bed material at a superficial gas velocity of approximately 3.6 ft/s (1 m/s). The gas is introduced to the burner through a perforated-cone distributor near the bottom of the burner.

The burner is heated during startup and tailburning phases with an induction heater and cooled during combustion with an external air-cooled jacket.

The burner is operated semicontinuously, with bed material (product solids) discharged in batches every 8 h and fresh feed bunker is subsequently filled in batches every 8 h. (Note: The initial batch requires approximately a 40-h cycle.) Fresh feed is added continuously to the burner.

7.2.2.2 JUPITER Burner System

The JUPITER burner system also uses a vertical cylindrical vessel for burning crushed irradiated fuel elements. The vessel inside diameter is 12 in. (30 cm). The crushed feed 1/16 in. (≤1.5 mm) ring size is introduced to the burner continuously, but bed material (product solids) is withdrawn in batches (0.09 kg each h). The equivalent burn rate is 6.6 lb/h (8.3×10^{-4} kg/s).

The burner is operated at approximately 800°C (1472°F) during equilibrium combustion periods. The operating pressure at the gas distributor is approximately 0.9 psig (7 kPa) = 600 mm H_2O.

The JUPITER burner also uses gaseous CO_2 and O_2 to fluidize the bed material at a superficial gas velocity of approximately 0.36 ft/s (0.11 m/s). The gas is introduced to the burner through a multiple (concentric) cone distributor near the bottom of the burner.

The burner is heated during startup and tailburning phases with hot gaseous CO_2 and nitrogen (N_2). The CO_2 flows through the fluidized bed, and the N_2 flows through an external jacket. Both gases are preheated with a resistance heater. The burner is cooled during combustion with gaseous N_2 flowing through the same external jacket.

7.2.3 Assessment

The assessment of HET/JUPITER fuel element burning systems is presented in two parts; they are, findings and conclusions. Section 7.2.3.1 gives the assessment team's findings which expand the technical issues listed in Appendix A2 and B2. Section 7.2.3.2 gives the team's conclusions concerning the scope of future cooperative work to resolve common technical issues.

7.2.3.1 Findings

A comparison of HET and JUPITER burner system characterized is given in Table 7.3.

The specific technical issues to be resolved by the HET and JUPITER Projects are common to both projects and are listed below.

- Material holdup and decontamination.
- Irradiated particle breakage.
- Bed fluidization properties and control.
- Buildup of oxides, hulls, and fission products in the fines system.

Table 7.3. HET/JUPITER burner system characteristics

	JUPITER	HET
1. Heating	Burner is heated with 12–16 h by preheated N_2. This N_2 is preheated by resistance heaters.	Coil induction heating in 90 min to 700°C. During burning temperature wall = 800–850°.
2. Flowing Gas velocity at main temperature	0.1 m/s	1.2 m/s
3. Burner Diameter	0.3 m	0.2 m
4. Main Graphite Particle Diameter	400 μm (crushed) 1500 μm (max) 50–100 μm during running	1100–1200 μm (crushed) 5000 μm (max) 500–600 μm during running
5. Off-Gas Treatment	Cyclones, blowback filters, feeding with screw conveyer into the bottom of reactor 1–4 kg/h Pressure: 0.4–0.6 bar	Cyclone, blowback filters, gravity system; fines flow together with fresh feed into the mid of reactor 150 kg/h Pressure: equal burner press
6. Pressure in Reactor	− 200 mm H_2O on top + 400– 600 mm H_2O at the bottom	∿ 600 mm H_2O on top ∿ 2100 mm H_2O at the bottom
7. Agglomeration	Agglomeration of $(Th,U)O_2$-particles not expected	No agglomeration at all (only 4–5 mm); depends on the high flow velocity
8. Remote Technology	Full remote technology in hot cell	Full remote technology is planned
9. Nonmetallic Material Resisting to Radiation of 10^8 Rad	10^8 rad When 10^6 rad: lead using	Material for radiation of 10^4 rad/h
10. Reactor Material	Incoloy 800 800°C (100 h, TUV) or 700°C 10^5 h	Hastelloy X 1100°C during heating time; 900°C during running

Table 7.3. (Continued)

JUPITER	HET
11. Particle Breakage After Crushing	
14%	4–8%
12. Product Removal	
2 interlocking valves: one valve is proportioning. Batchwise removal (90 g HM per batch); manual transport	Removal by opening the knifegates in the vertex pipe; pneumatic transport by vacuum

- Distribution of fission-product plateout.
- Particle agglomeration.
- Fission-product corrosion and migration into burner materials.
- Fission-product decay-heat effects on burner cooling and heatup time.
- Maintenance-philosophy verification.

The importance of each of these issues to the HET and JUPITER Projects is discussed in Appendices A2 and B2, respectively.

7.2.3.2 Conclusions

Conclusions on each technical issue is provided below. A tabular summary of these conclusions is provided in Table 7.4.

Material Holdup and Accountability. Methods for SNM accountability control and decontamination procedures used in the HET and JUPITER Projects are of common interest and can be tested and evaluated by either project, despite differences in fuels and burner geometry.

Irradiated Particle Behavior. Exchange of technical information on irradiated-particle behavior breakage, agglomeration, fission-product plateout, corrosion, and heat effects; and buildup of inerts and fission products throughout the system will be fruitful. Although the superficial gas velocity and lower-bed temperature in the JUPITER burner are expected to reduce the magnitude of many of these effects, the reduction will be at least partly offset by greater radioactivity release from the BISO-coated AVR fuel (JUPITER) than from the TRISO-coated FSV fuel (HET). Therefore, the resultant particle behavior may be comparable in both systems.

Burner Control. The HET and JUPITER burners are operated and controlled similarly, even though the process conditions and hardware are somewhat different. Useful information can be exchanged to compare methods and procedures for bed fluidization, bed-temperature control, burner vessel temperature control, the effects of gas velocity on bed mixing and heat transfer, product-solids removal, and burner off-gas cleanup.

Table 7.4. Fuel Element Burning Conclusion Summary

HET Technical Issue	Obtainable from JUPITER	Comment
1. Material holdup and decontamination	YES	• Quantitative data available from JUPITER; HET and JUPITER have nearly equivalent throughputs
2. Irradiated particle breakage	YES	• Qualtitative data possible, differences in fuel particle types (JUPITER-BISO, HET-TRISO) preclude any direct comparison
3. Fluidization properties and control	YES	• Quantitative data available from JUPITER topically includes effects of gas velocity on bed mixing, heat transfer, product-solids removal, and burner off-gas cleanup.
4. Buildup of oxides, SiC Hulls, and fission products in fines recycle system	YES	• JUPITER system utilizes a gravity feed fines recycle system that is similar to the HET design. Data transfer is possible on oxide and fission product buildup.
5. Distribution of fission product plate-out	YES	• Although JUPITER bed temperatures are lower than for the HET burner, BISO (AVR) particles are expected to yield somewhat greater releases of fission products. JUPITER data would be very useful to prototype designs.
6. Particle agglomeration due to fission products	YES	• This issue is expected to be a bigger problem with carbide (HET type) fuels than with (oxide JUPITER type). JUPITER data would be very useful to prototype designs.
7. Fission product corrosion of burner components	YES	• JUPITER burner material is Incoloy 800, HET uses Hastelloy-X; JUPITER experience would be useful in evaluation of materials for prototype systems.
8. Additional cooling requirements due to fission product decay-heat	YES	• JUPITER data would be useful to establish design limits for burner cooling subsystems. Heat load arising from fission product decay is substantial - even during nonoperating modes.
9. Reduced heating requirements due to fission product decay-heat	YES	• JUPITER data would be useful to establish design limits for burner heating systems. Fission product decay heat is important to burner startup operations.
10. Maintenance philosophy	YES	• JUPITER and HET utilize the same design concept-fluidized bed burners - data transfer possible.

Burner Corrosion. Exchange of corrosion experience with the HET and JUPITER burners will allow a comparison of Hastelloy-X (HET) and Incoloy-800 (JUPITER) resistance to fission-product attack and migration. Such a comparison will be useful in evaluation of materials for prototype systems.

Maintenance Philosophy. Maintainability data from HET and JUPITER burner systems are of mutual interest because of similarities in burner system configuration, process hot-cell design and layout, and remote-maintenance philosophy (remove-and-replace).

7.3 DISSOLUTION/FEED ADJUSTMENT

Appendices A3 and B3 are technical summaries of the HET and JUPITER dissolution and feed adjustment systems. This section consolidates these summaries.

7.3.1 Scope of Technical Issues

The principal requirement of the HET and JUPITER dissolution and feed adjustment systems is to receive burner ash, dissolve the heavy-metal bearing solids into an aqueous solution, separate and dry insols, and adjust the solution to conditions required for solvent extraction feed. Although the HET and JUPITER systems are designed differently, the scope of common technical issues is summarized as follows:

- the effects of fuel irradiation and fission products on the efficiency of dissolution, insols separation, and insols drying and
- the effects of fission products on feed adjustment and storage.

7.3.2 Design Solutions

7.3.2.1 HET Dissolution/Feed Adjustment System

A process flow diagram for HET dissolution/feed adjustment is shown in Fig. 7.1. The system offers the capability to process fissile and fertile particles separately.

The same basic equipment is used for both processes with the notable exception of the fissile stream, where the composition of dissolver acid is changed and the feed adjustment step is omitted.

7.3.2.1.1 Dissolution. Based on the assay of the canned secondary burner ash from thorium-bearing fuels, sufficient dissolver acid is added to the dissolver to yield a 1 M Th solution. The dissolver acid composition is 13 M HNO_3, 0.05 MF, and 0.10 M Al^{+3}. It also contains some nuclear poison for nuclear criticality safety purposes. For uranium only particles, the acid volume is based on a final uranium concentration of 0.06 molar and the dissolver acid composition is 4.6 M HNO_3 plus the soluble neutron poison. The burner ash in the transfer can is moved to the dissolver through the dump valve. The dissolver is then heated to boiling by turning on the steam to the lower jacket. The contents are maintained at the boiling temperature until dissolution of the uranium and thorium has been completed. The SiC hulls, residual graphite and some fission products will not dissolve. The vapors are condensed in a water-cooled reflux condenser with the condesation returning to the dissolver and the noncondensables vented to the off-gas system.

The dissolver is a vertical tube vessel with a conical bottom and separate steam jackets for the bottom and the vessel sides. The vessel is insulated with stainless steel cladding over the insulation. The vessel and jackets are fabricated from 304 L stainless steel. The vessel dimensions are 12 in. I.D. by 46 in. long and has a working capacity of 65 liters. The vessel is fitted with a 304 L stainless steel submerged

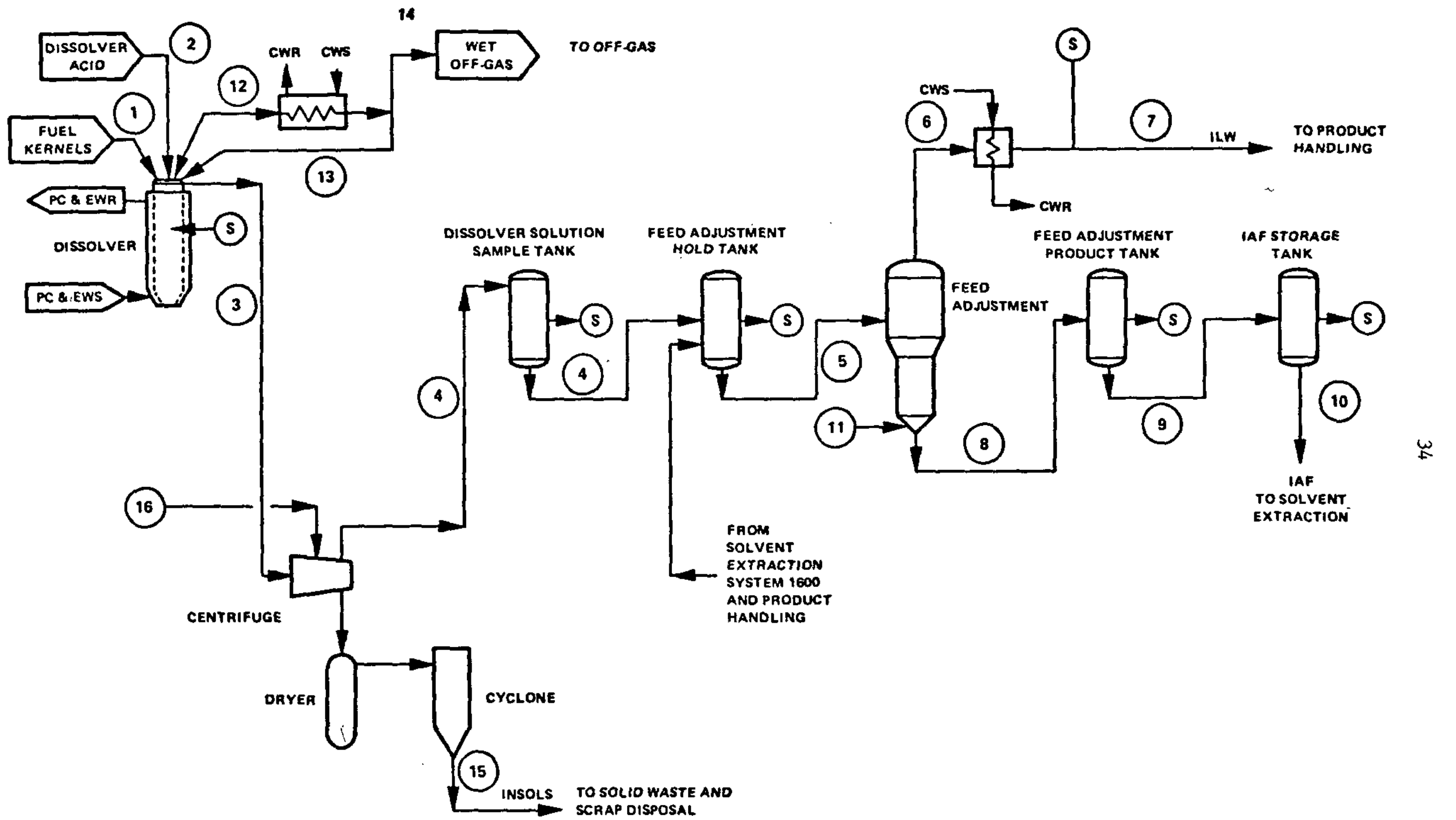


Fig. 7.1. Dissolution and Feed Adjustment Process Flow Diagram.

jet for emptying which is operated on 90 psig steam and has a transfer capacity of 8 liters/min. The vessel is fitted with a single pass downdraft condensor.

7.3.2.1.2 Solid-Liquid Separation. On completion of dissolution, the steam is turned off and the jacket cooling water is turned on. After cooling, the dissolver solution along with the insols (SiC hull, graphite and some fission products) are fed to the continuous centrifuge by means of the submerged steam jet. The clarified dissolver solution drains to the dissolver solution sample tank and the insols on the first pass fall into the transfer can. Water containing a soluble neutron poison is also metered into the centrifuge to wash the separated solids. The wash solution combines with the dissolver solution. The insols are returned to the empty dissolver on a second pass for repulping; (i.e., washing with a water solution containing a soluble neutron poison). The repulped solution is clarified by centrifugation on the second pass in the same manner as the first pass dissolver solution with the wash solution being combined with the dissolver solution.

The centrifuge is a Bird 6 in. continuous centrifuge. The centrifuge bowl is constructed of 304 ELC with coated wear surfaces. The centrifuge is driven by a 7.5 hp electric motor.

7.3.2.1.3 Insol Drying. The washed insols from the centrifuge fall into the insols dryer. Hot air is used to effect the drying and to fluidize the insols. The dryer off-gas is discharged to the dissolver off-gas system and the dried insols are elutriated to the cyclone, separated and drained to the transfer can and returned.

The Insols Dryer is a vertical vessel 50 in. long by 4 in. and 5 in. in diam. fabricated from 304 L stainless steel. It is fitted with a cyclone separator 16 in. long by 5 in. I.D. with a 0.203 in. wall that is fabricated from 304 L stainless steel. A filter chamber 20 in. long by 4 in. I.D. with a 0.120 in. wall, 304 L stainless steel is fitted with two 1 in diam. by 17 in. long 304 stainless steel sintered metal blowback filters. Design pressure is 25 psig air at 680 SLPH flow.

7.3.2.1.4 Feed Adjustment. The dissolver and insols wash solutions are mixed in the dissolver solution sample tank by air sparging, sampled for accountability and transferred by a steam jet to the feed adjustment hold tank for surge or storage. Thorium-bearing dissolver solution is processed through feed adjustment to reduce the nitric acid concentration to 1 molar and to increase the thorium concentration to 1.5 molar. In the feed adjustment unit, the dissolver solution is concentrated batchwise by evaporation to a molten salt (boiling point of 130 to 135°C) and then sparged with steam to vaporize the excess nitric acid. A steam coil provides the heat for evaporation. The capability for addition of formic acid is provided for the control of Ruthenium volatility. The vapors are condensed in a water-cooled condenser and routed to the intermediate level waste collection tank. When sufficient nitric acid has been removed, the steam sparger is discontinued and the steam to the coils turned off. The solution is then diluted with distilled water to 1.5 M Th, mixed by sparging and steam jet transferred to the Feed Adjustment Product Tank. Here the solution is sampled for composition verification and adjustments made by the addition of nitric acid or distilled water. Uranium only fuel (FSV Segment 9 fissile particles) does not require removal of excess nitric acid. The feed adjustment unit would be used only to effect any necessary feed concentration.

The Feed Adjustment Tank is a dual diameter vertical vessel fabricated from 304 L stainless steel and has a conical bottom and is fitted with a 304 L heating and cooling coil fabricated from 304 L tubing with 1/2 in. O.D. The lower vessel is schedule 40S 8-in-diam. pipe. The upper vessel is schedule 40S 12-in.-diam. pipe. The working volume is 35 liters.

7.3.2.2 JUPITER Dissolution/Feed Adjustment System

The JUPITER dissolution/feed adjustment system utilizes a single upflow continuous dissolver and three circulation evaporators.

7.3.2.2.1 Dissolver. The material to be dissolved consists of thorium and uranium mixed oxide particles and is suitable for a continuous dissolution process. The dissolver used for this step essentially consists of a cylindrical vessel with a hemispherhical bottom and a conical top part, which accommodates the connections for the particle inlet, dissolving reagent inlet, etc. (Fig. 7.2). The dissolving reagent (Thorex reagent) is a mixture of 13 M HNO_3, 0.1 M $Al(NO_3)_3$, and 0.05 M HF. The reagent is preheated outside the dissolver and is fed into the dissolver via a central inlet tube reaching down to the bottom of the vessel. The particles are fed in by means of a screw feeder.

7.3.2.2.2 Evaporator. Three circulation evaporators of identical design (Fig. 7.3) are used for adjusting the feed solutions for the various extraction cycles and for concentrating the uranium product. The operation is semicontinuous (i.e., the feed solution is admitted continuously, the vapors are extracted continuously, and only the concentrate is extracted in batches when it reaches a certain level in the sump). When *acid-deficient* feed solutions are prepared (three), the steam stripping can be followed by condensation of the steam in the condenser incorporated in the head of the evaporator. Thus, safe dilution of the highly viscous sump product is possible.

Concentration of the spent process acid is carried out in a special circulation evaporator followed by a packed column. The evaporation process is semicontinuous, with the reflux ratio in the column being continuously adjusted to the rising concentration in the sump fraction. Besides the apparatus mentioned above, the chemical processing part of the plant also includes several cylindircal and criticality-safe slab-shaped vessels (capacities ranging from 1–250 liters), piping lines with nominal diameters ranging from 4–12 mm, necessary isolation and control valves, and the process instrumentation.

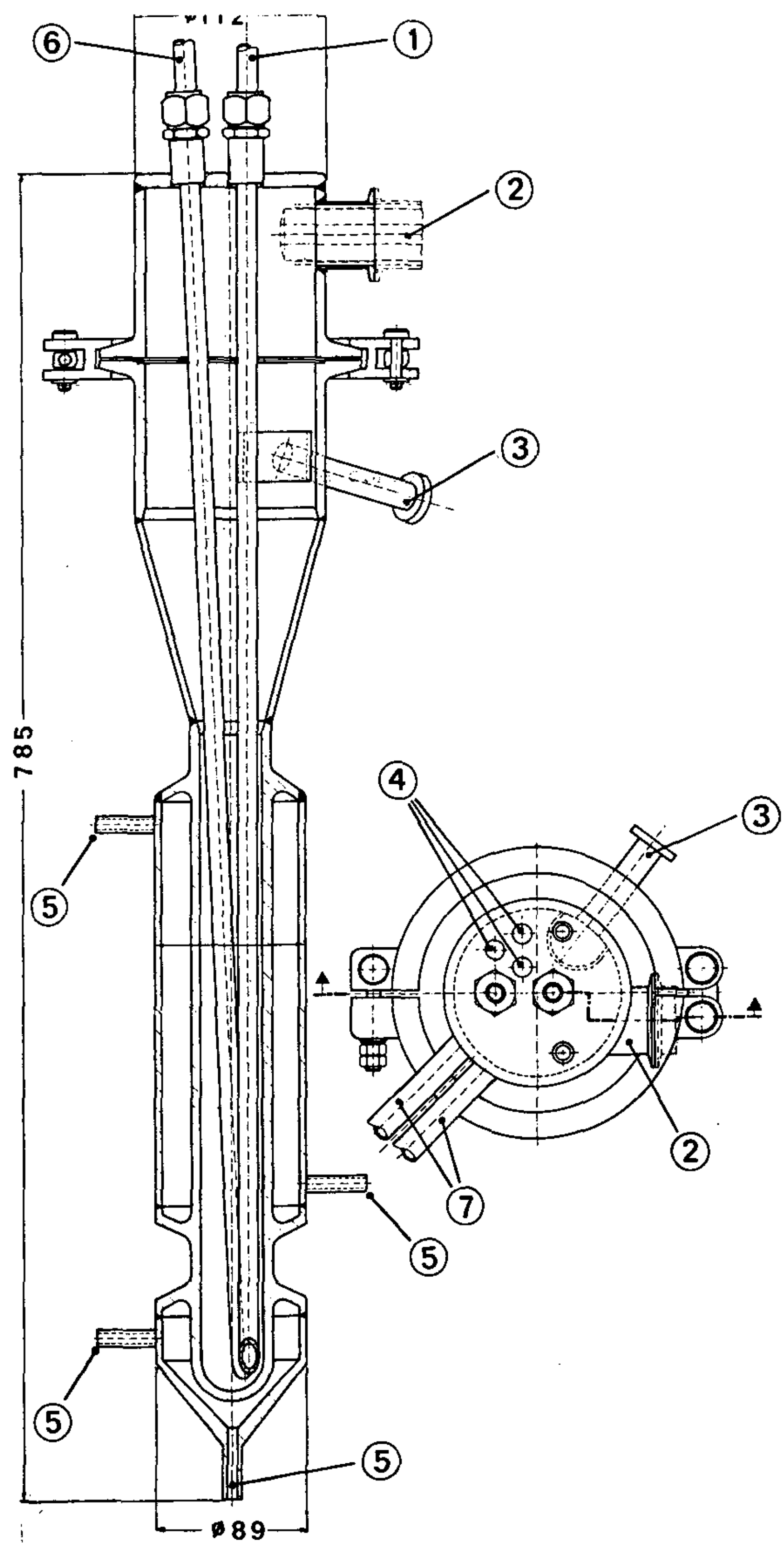


Fig. 7.2. Upflow Continuous Dissolver.

1 Thorex Inlet; 2 Particles Inlet; 3 Product Outlet; 4 Dip Tubes; 5 Steam Connections; 6 Emptying Pipe; 7 Vapor Lines

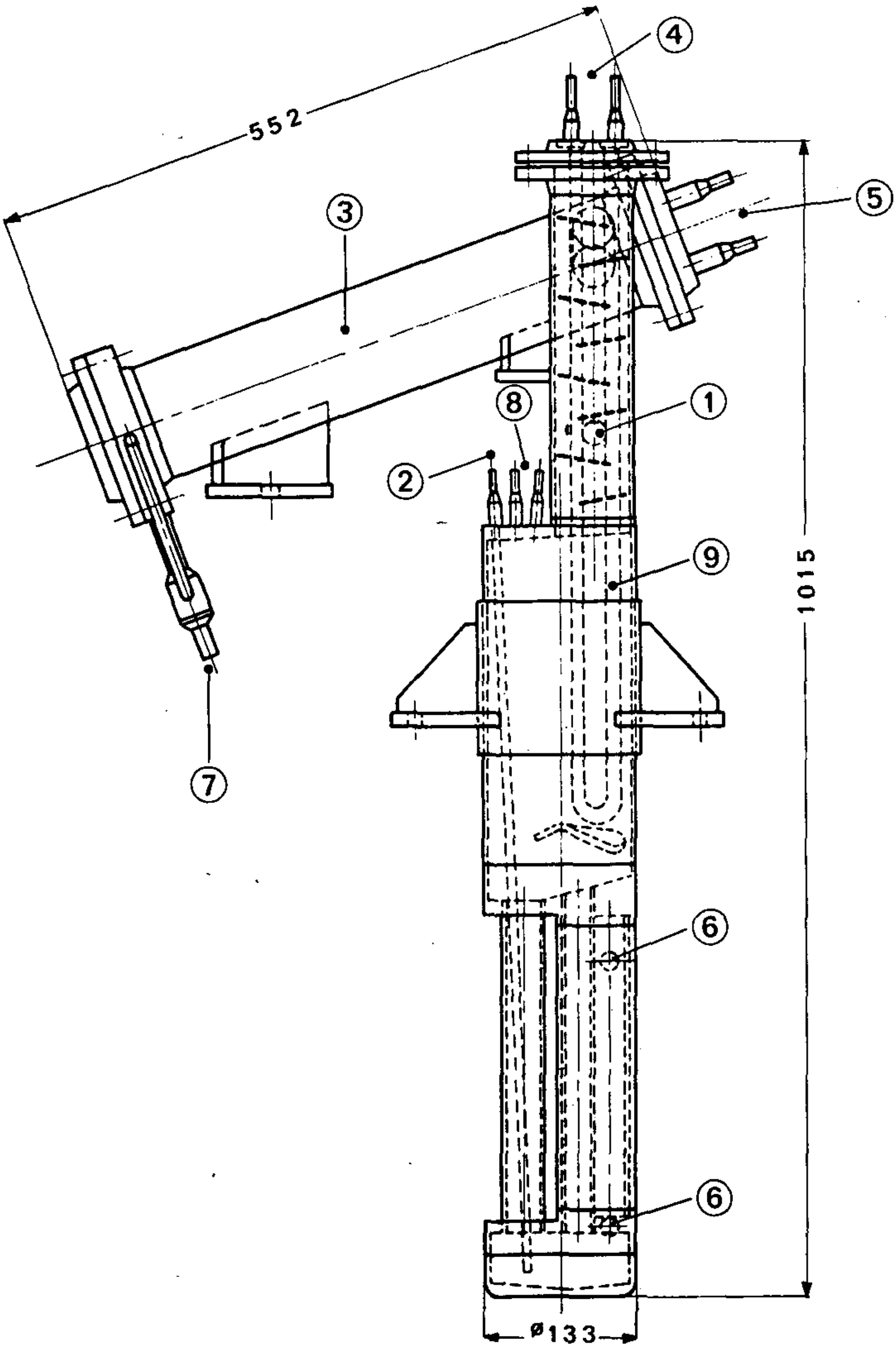


Fig. 7.3. Circulation Evaporator.

1 Feed Inlet; 2 Product Outlet; 3 Condenser;
4,5 Cooling Water Connections; 6 Steam Connections;
7 Condensate Outlet; 8 Instrument Piping; 9 Incorporated Cooling System

7.3.2.2.3 Solid-Liquid Separation. On completion of dissolution and/or feed adjustment, the solutions are cooled and fed to an insols separation system. The system is fabricated from stainless steel (1.4306) and equipped with polypropylene throw-away filters. The clarified solutions are metered to interstage process vessles; the filters are removed from the insols separation system, analyzed by nondestructive methods, and sent to waste.

7.3.3 Assessment

The assessment of HET/JUPITER dissolution/feed adjustment systems is presented in two parts; they are, findings and conclusions. Section 7.3.3.1 gives the assessment team's findings, elaborating on the technical issues listed in Appendix A3 and B3. Section 7.3.3.2 gives the team's conclusions concerning the scope of future cooperative work to resolve common technical issues.

7.3.3.1 Findings

Specific technical issues to be resolved by the HET and JUPITER Projects are common to both projects and are listed below.

1. Dissolution rate as a function of irradiation history.
2. Stability of fission products in feed.
3. Characterization of insols.

The specific importance of each of these issues to the HET and JUPITER Projects is discussed in Appendices A3 and B3, respectively.

7.3.3.2 Conclusions

Conclusions on each technical issue is provided below. A tabular summary of these conclusions is provided in Table 7.5.

Dissolution Rate. The specific dissolution rate of HET and JUPITER fuel is expected to be different because of different fuel material to be processed. The HET fuel is a mixture of ThO_2 and U_3O_8 resulting from the conversion of ThC_2 and UC_2, whereas the JUPITER fuel is a mixed $(Th,U)O_2$. Both HET and JUPITER design values are based on cold data and some change may result from the presence of irradiated fuel. These changes, however, are not expected to be significant and can easily be offset by improvements in operating procedures.

SiC Hull Separation. Comparison of HET and JUPITER data on this technical issue is not possible because of basic differences in the respective fuels to be processed. HET will process fuel with SiC hulls and JUPITER will process fuels without SiC hulls.

Characterization of Insols. With the above noted exception of insoluble SiC, characterization of the insoluble residues, graphite, and unburned fuel particles is possible. The characterization of such insolubles is an important flowsheet and waste disposal consideration.

Table 7.5. Dissolution and Feed Adjustment Conclusion Summary

	HET Technical Issues	Obtainable from JUPITER	Comment
1.	Dissolution rate as a function of irradiation history	YES	• JUPITER dissolution rate based on cold data ∿4–6 kg/day (24 hr day) • JUPITER design estimate conservative at 2kg/day • HET design requirement 2–3kg/day (16 hr day)
2.	Fission product, boron and fluoride volatility and iodine retention	NO	• formic acid is not used by JUPITER to suppress the volatility of ruthenium • presence of iodine diminished by decay-AVR fuel for JUPITER is now 3–4 years old • JUPITER to effect Zr and Mo control by dissolution under boiling and slight vacuum conditions
3.	Demonstrate effectiveness of hull separation and washing	NO	• JUPITER fuel particles are BISO coated and do not have silicon carbide coatings
4.	Characterize SiC hulls and other insols	NO/YES	• see above comment on silicon carbide (SiC) hulls • other insols (graphite, unburned particles, and residues) can be characterized
5.	Stability of fission products in feed	YES	• fission product stability impacts feed adjustment and steam stripping operations under acid-deficient conditions • *fission product control* by adjusting acid level to 0.15M • normal acid feed 0.7–1.1M

7.4 SOLVENT EXTRACTION

Appendix A4 and B4 are technical summaries of the HET and JUPITER Project solvent extraction system. This section consolidates these summaries.

7.4.1 Scope of Technical Issues

The principal requirement of the HET and JUPITER solvent extraction system is to separate the constituents of aqueous solutions made from spent reactor fuel. The desired separations include (1) heavy metal actinides from associated fission products and (2) heavy metal actinides from each other.

Both the HET and JUPITER flowsheets utilize liquid-liquid solvent extraction to effect these separations and are concerned with the following technical issues:

- operability of the acid-Thorex processes and
- solvent stability in a radiation environment.

Concern regarding the operability of the acid-Thorex process centers on overall flowsheet performance. The attendant influence of (1) solvent degradation products, (2) the presence of carbonaceous materials in the feed, and (3) formation of emulsions separately or collectively limit achievable throughputs and thereby impact overall flowsheet performance.

Solvent stability in an intense environment of β and γ radiation is an important technical issue. The importance of solvent stability under these conditions follows from the basic principle of solvent extraction. Separation of constituents of an aqueous solution of spent reactor fuel is achieved by creating an interface between the aqueous and organic liquid; the constituents with greatest solubility in the organic (solvent) liquid resides there leaving behind other constituents. The degradation (formation of polymers, insoluble complexes) of solvent under irradiation greatly inhibits the ability to accomplish the required separation of aqueous solution constituents by this method.

7.4.2 Design Solutions

7.4.2.1 HET Solvent Extraction

The HET solvent extraction system utilized the pulsed, countercurrent (aqueous, organic phases), column technique. The system is designed to partially purify and separate thorium and uranium from fission products, chemical impurities, and from each other (acid-Thorex Process). The systems will also accept uranium-bearing solutions and separate uranium from fission products and chemical impurities (modified Purex). The HET solvent extraction system provides the following functional capabilities:

- extraction of uranium and thorium from gross fission products and other contaminants in the dissolver feed solution,
- thorium partitioning by back-extraction into the aqueous phase,
- uranium partitioning by back-extraction into the aqueous phase, and
- solvent cleanup and recycle.

The process flow diagram solvent extraction is shown in Fig. 7.4.

The acid-Thorex process is the principle operating mode for HET solvent extraction. Clarified and adjusted dissolver solution is fed to the extraction column and thorium and uranium is extracted into the organic solvent (30% TBP in kerosene). Fission products and other impurities contained in the aqueous phase are collected as stream 1AW and discharged to liquid waste.

The uranium- and thorium-bearing solvent stream, 1AP, is transferred to the partition column where the thorium is selectively stripped into the aqueous phase, stream 1BXT. The uranium-bearing solvent stream 1BU is transferred to the final stripping column.

The thorium containing aqueous stream, 1BXT, is contacted with solvent in the partition-scrub column to extract any remaining uranium from the aqueous stream. The solvent-bearing uranium stream, 1BSU, is

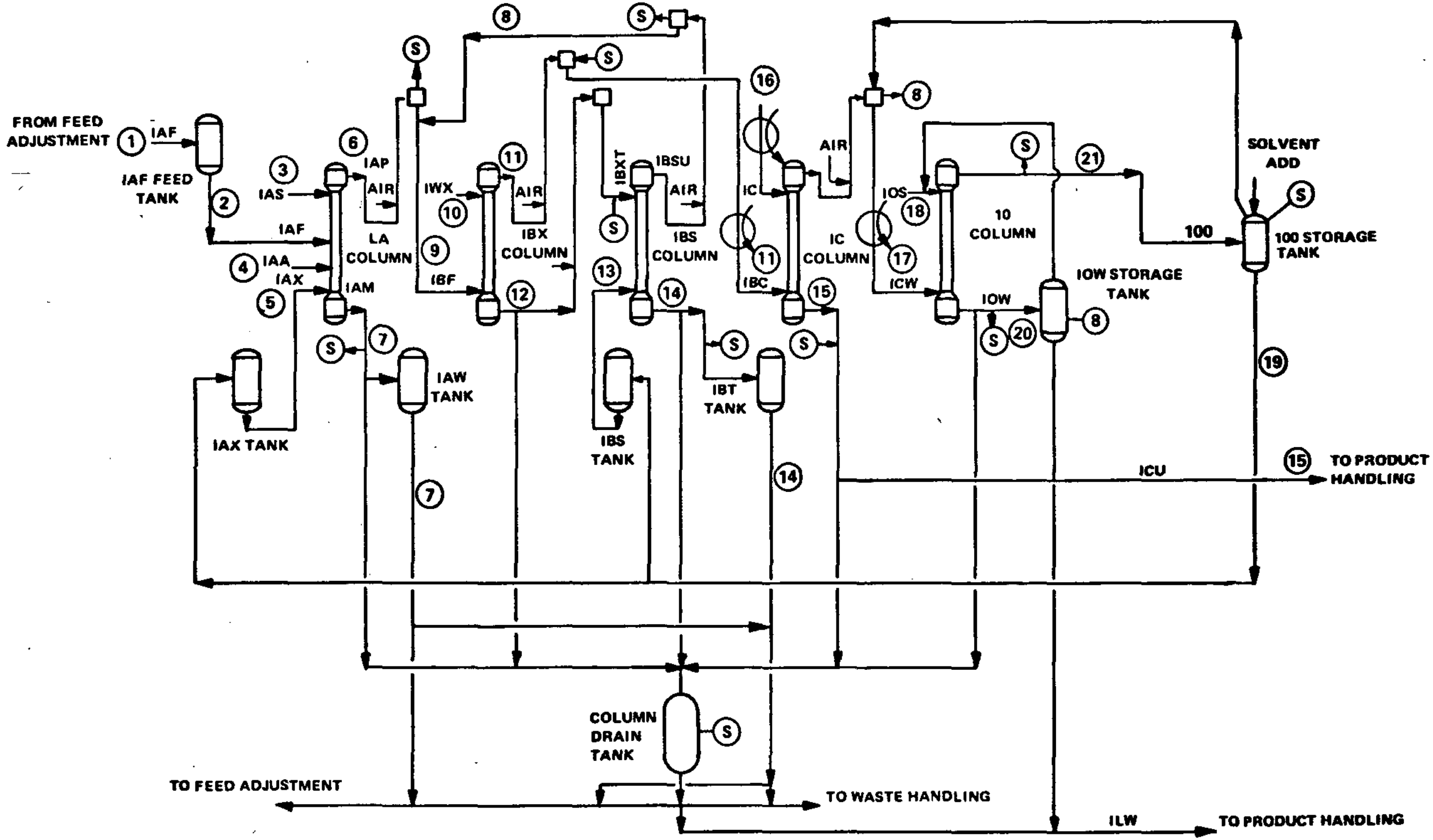


Fig. 7.4. HET Solvent Extraction System.

back-cycled and combined with partition column feed, 1AP. The thorium aqueous stream, 1BT, is collected and discharged to liquid waste.

The scrubbed uranium-bearing solvent stream, 1BU, is stripped of the uranium in the final stripping column. The aqueous uranium stream, ICU, is transferred for concentration. The stripped solvent stream is regenerated and recycled to the extraction and partition-scrub columns. Aqueous wastes from solvent regeneration is transferred to storage as intermediate level liquid waste.

The solvent extraction system is designed for the processing of both thorium-bearing fuel and uranium-only fuel in separate campaigns. For thorium fuels, the acid-Thorex process is used and a modified Purex process is used for the uranium-only fuel particles. The modified Purex process used differs from the Purex process employed for LWR fuel in that the feed is much more dilute and the plutonium (predominately ^{238}Pu) is not recovered. The same equipment is used for both fuel types, but the flow patterns differ somewhat. Both processes use the same solvent, the same salting agent (nitric acid), and the same contactors (pulse columns). The stream compositions and flow rates differ between the two processes.

7.4.2.1.1 <u>Extraction Column</u>. This column is fed from two tanks, 1AF, of small diameter to provide verification of the feed rate by drop-out measurement.

The 1AF stream is metered into the midpoint of the 1A Extraction column by means of a control valve and a drop-out rate controller using the two 1AF tanks alternately. Gravity flow is used. A solvent stream (1AX) is metered into the bottom of the column from the 1AX Tank by means of the 1A Column Pump, a flow control loop, and the extraction column contents should the 1A Column Pump fail.

The solvent flows upward through the column countercurrent to the aqueous stream, 1AF, and preferrentially extracts the uranium and the thorium leaving the bulk of the fission products and other chemicals in the aqueous phase. A 13 $\underline{M}$ HNO_3 stream (1AA) is metered into the lower portion of the Extraction Column to provide the salting strength needed for uranium and thorium extracting where the thorium concentration is low and the self-salting effects minimal. A 1 M HNO_3 stream (1AS) is metered into the top of the Extraction Column to scrub back into the aqueous phase the small fraction of the fission products that were extracted into the solvent in the lower portion of the column. Both the 1AA and 1AS streams originate from the chemical makeup systems and are controlled by flow control loops.

The aqueous waste stream (1AW) leaves the bottom of the Extraction Column and flows into the 1AW tank. The 1AW flow rate is controlled to maintain a fixed Extraction Column interface position between the aqueous and solvent phases. After sampling for heavy metal accountability, the 1AW is transferred batchwise by a steam jet to high level waste.

The column dimensions are 1 in. I.D., 18 ft. long, and 21 ft. overall length with nozzle plates (1/8 in. holes, 25% free area) spaced at two in. increments. The disengaging sections are fitted to each end 4 in. I.D. at bottom, 2 in. I.D. at top, both 18 in. in length. Column construction is from 304 L stainless steel.

7.4.2.1.2 Partition Column. The uranium- and thorium-bearing solvent streams (1AP) exit the Extraction Column, is air lifted to the 1BX Column Head Tank, and flows by gravity into the bottom of the Partition Column. The 0.2 M HNO_3, 5×10^{-3} M F^-, 1BX stream is metered into the top of the Partition Column from the Chemical Makeup System. The 1BX stream flows countercurrent to the solvent perferentially stripping all of the thorium and a small amount of the uranium from the solvent and exits the bottom of the column as the 1BXT stream. The 1BXT stream flow rate is controlled to maintain a fixed interface position in the Partition Column. The column dimensions are 15-ft.-long center section, 1 1/2-in. I.D. with a 3-in. I.D. by 12-in.-long disengaging section at the bottom and a 3-in. I.D. by 24-in.-long section at the top. The column is filled with nozzle plates (3/16-in. holes, 25% free area) on 4-in. spacings (bottom seven foot) and 2-in. spacing (top 8 ft. of center section). Column construction is from 304 L stainless steel.

7.4.2.1.3 Partition Scrub Column. The 1BXT stream is air lifted to the 1BS column head tank and drains into the top of the Partition Scrub Column. A clean solvent stream (1BS) of the same composition as the 1AX stream is metered into the bottom of the Partition Scrub Column from the 1BS Tank in the same manner as the 1AX stream. The 1BS stream back extracts the small amount of uranium stripped from the solvent in the Partition Column. The back-extracted uranium exits the Partition Scrub Column, as the 1BSU stream is air lifted to the 1BS recycle head tank, and drains to the bottom of the Partition Column where it is combined with the 1AP feed stream.

The aqueous stream (1BT) from the Partition Scrub Column contains essentially all of the thorium and only a trace of uranium. Its flow rate is controlled by the Partition Scrub Column interface position. The 1BT stream flows to the 1BT Tank where it is sampled for accountability and batch transferred by a steam jet to the Intermediate Level Waste Tank.

The 1BS column is fabricated of 304 L stainless steel and has an overall height of 15 1/2 ft. The central section of the column is fabricated of 1-in. I.D. tubing, 13 ft. in length. The column plates are 1/8 in. hole, nozzles 23% free area with 2-in. plate spacing. The nozzles are pointed up. The disengaging sections are 3-in. I.D. by 12 in. at the bottom and 2-in. I.D. by 18 in. at the top. The top disengaging section is fitted with dip tubes for interface control.

7.4.2.1.4 Stripping Column. The Stripping Column receives the uranium-bearing solvent stream (1BU) from the Partition Column. This stream is air-lifted to the 1CU column head tank and introduced to the bottom of the Strip Column.

The 1CX stream (0.01 $\underline{M}$ HNO_3, 1×10^{-3} $\underline{M}$ F^-) is metered into the top of the Strip Column from the Chemical Makeup System. As the 1CX flows countercurrent to the 1BU, it strips the uranium from the solvent. The uranium-bearing aqueous stream (1CU) flows out of the bottom of the Strip Column at a rate controlled by the Strip Column interface position. It is air-lifted to the Concentrator Head Tank and drains to a uranium concentrator system. The Strip Column is monitored at 50°C by heating of the 1BU and 1CX streams with hot water in heat exchangers. Heating the Strip Column improves its process performance.

The construction of this column is identical to the Partition Scrub Column with the exception that the center section is 13 ft. in length.

7.4.2.1.5 Solvent Regeneration. The stripped solvent (1CW stream) overflows the 1C Column, is air-lifted to the 10 column head tank and drains into the bottom of the Solvent Regeneration Column. A 0.25 M Na_2CO_3 solution (10S stream) is pumped into the top of the Solvent Regeneration Column from the 10W Tank with its flow rate controlled by a flow control loop. As the 10S flows countercurrent to the 1CW, it scrubs out solvent decomposition products, primarily dibutylphosphate. The aqueous stream (10W) exits the bottom of the column and flows back to the 10W tank at a rate controlled by the column interface position. Periodically, the 10W is transferred and a fresh sodium carbonate solution is added from the chemical makeup system. Line the 1C Column, the inlet streams are heated to improve process performance. The washed solvent overflows from the Solvent Regeneration Column into the 100 tank. Cooling coils in the 100 tank cool the solvent to about 25°C. As needed, the solvent is pumped from the 100 tank to the 1AX and 1BS tanks for reuse.

At the completion of a processing campaign, the 1AF stream is turned off, but the remainder of the process streams continue until the uranium and thorium have been stripped from the solvent extraction columns. The solvent is then displaced from the columns with aqueous streams and collected in the 100 tank. Next, the columns are emptied to the column drain tank by steam jets provided on each column for this purpose. After sampling, the column drain tank contents are jet transferred to waste.

The solvent wash 10 column is fabricated of 304 L stainless steel tubing and is 16 ft. tall overall. The center section is fabricated from 1 1/2 in. I.D. and is 13 ft. long. The plates are 1/8-in.-diam. holes, 23% free area nozzle plates with 2-in. spacing. The nozzles are pointed down. The end section of the column are made from 4 in. I.D. with 18-in.-long tubing at the bottom.

In the modified-PUREX operating mode, the following exceptions to the acid-Thorex process are applied. The processing of uranium-only fuels is similar to that described above for thorium-bearing fuels with the following exceptions:

- no 1AA stream is added;
- the 1AP stream flows through the 1BX Column to the 1C Column Head Tank and directly into the 1C Column, and the 1BSU stream is not operable;
- 1CS stream contains no fluoride; and
- flow rates and stream compositions are different.

7.4.2.2 JUPITER Solvent Extraction

The JUPITER solvent extraction system utilizes air-pulsed mixer settlers to decontaminate and recover heavy metal products. The mixer settler offers the combined advantages of reliability due to the absence of moving parts and operational flexibility.

The JUPITER mixer-settler design has a total of 16 stages and was designed especially for JUPITER. The design was based on experimental data developed at KFA. The following characteristics describe the design.[4]

Mixing chamber: 32 mm ϕ × 140 mm
Capacity 120 ml
Settling chamber: 26 mm × 26 mm × 170 mm
Capacity 120 ml

A total of five mixer settlers of identical design are used to study several process variations. Details of mixer-settler construction are shown in Fig. 7.5, and the function of these units is shown in the simplified process flow diagram of Fig. 7.6.

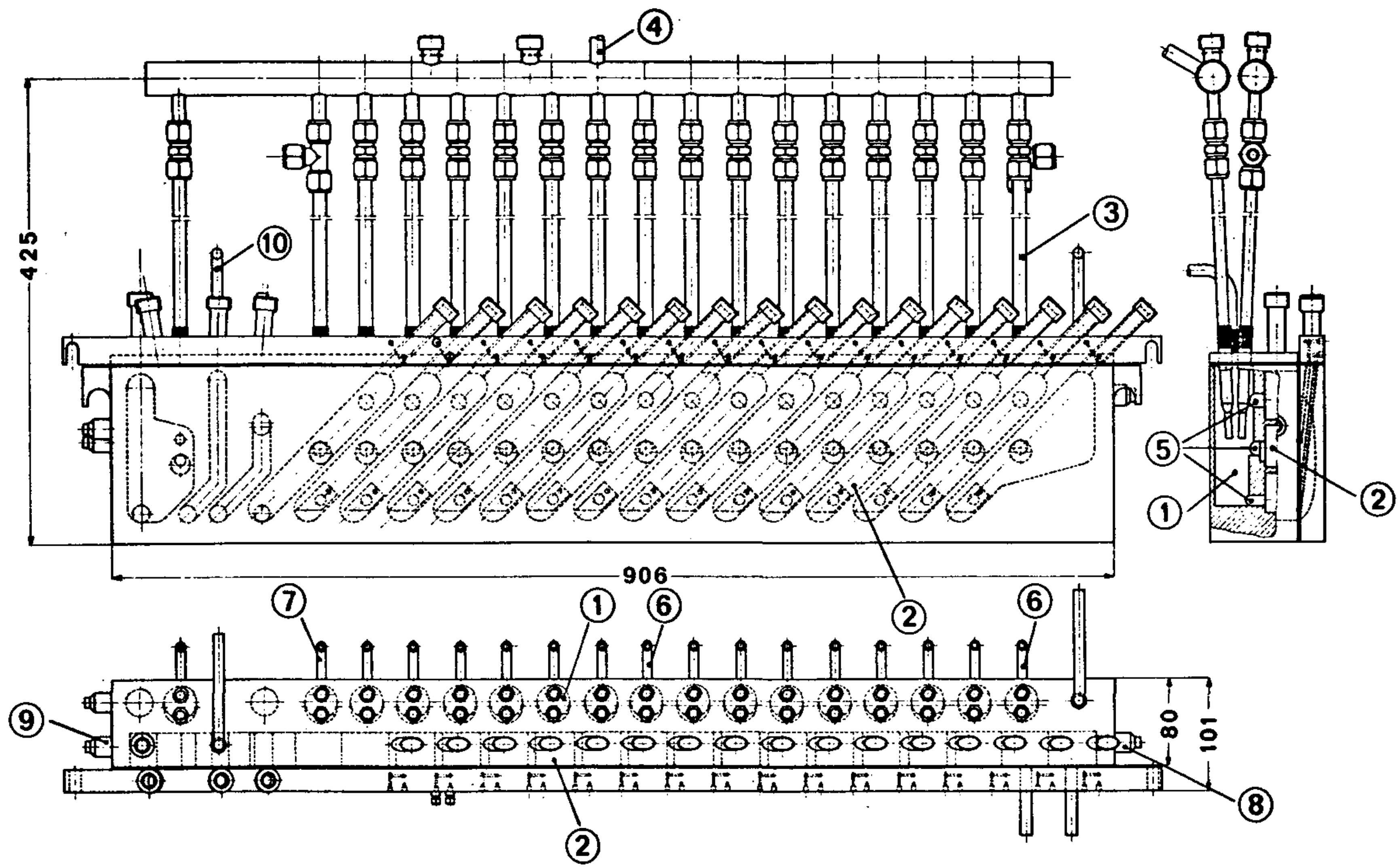


Fig. 7.5. Air Pulsed Mixer-Settler.

1 Mixing Chamber; 2 Settling Chamber; 3 Suction Pipe; 4 Vacuum Pipe; 5 Phase Ports, 6 Aqueous Feed Inlets; 7 Organic Feed Inlet; 8 Organic Phase Outlet; 9 Aqueous Phase Outlet; 10 Adjustable Overflow

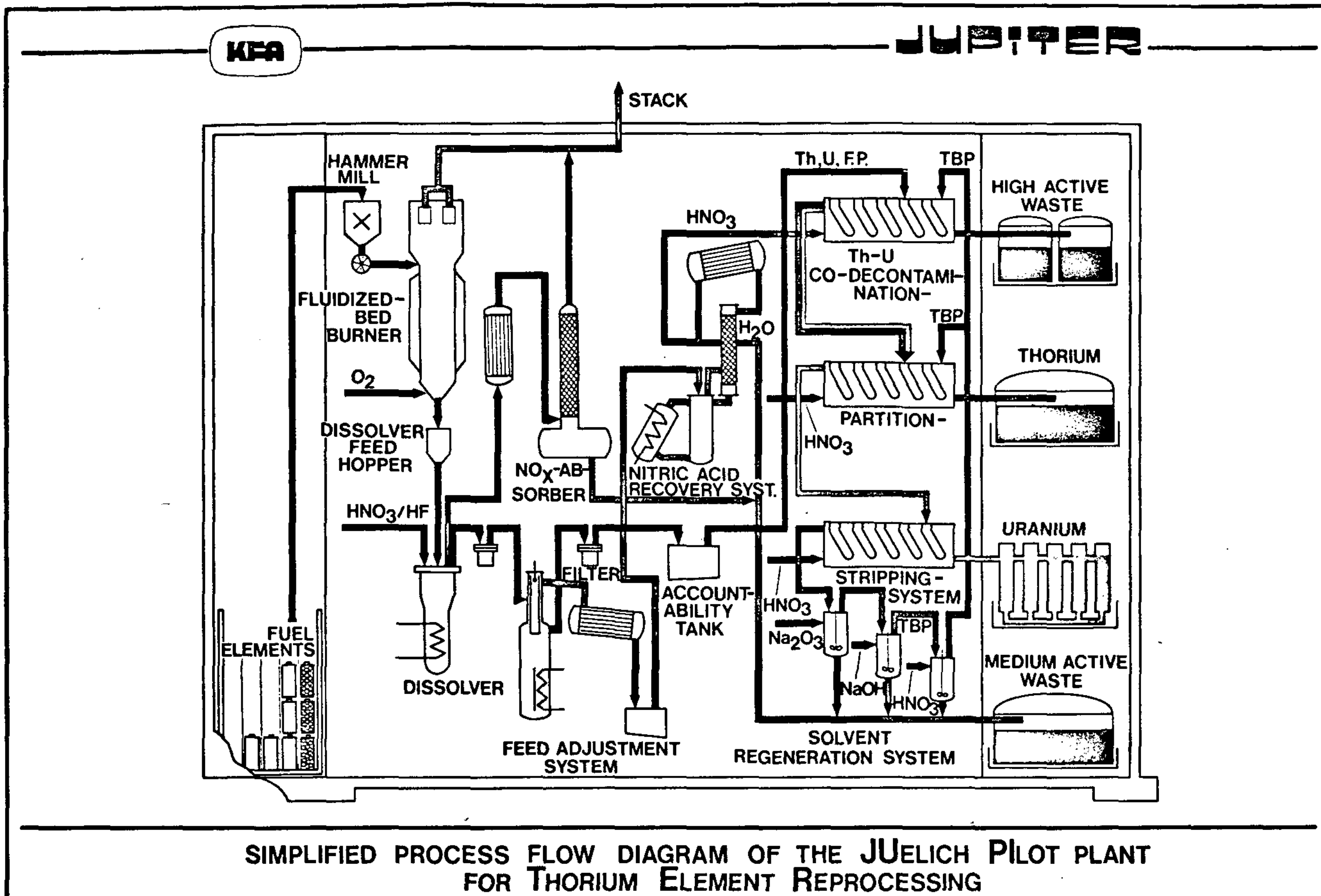


Fig. 7.6. Simplified Process Flow Diagram of the JUelich PIlot Plant for Thorium Element Reprocessing

The JUPITER flowsheet is organized to demonstrate the following solvent extraction processes:

- Thorex Process - two cycles,
- Thorex Process - one cycle,
- Interim 23 Process w/acid feed,
- Interim 23 Process w/acid-deficient feed, and
- Uranium purification.

7.4.2.2.1 Thorex Process - two cycles. This process utilizes all five JUPITER mixer settlers to produce separate aqueous streams of uranium and thorium.

In this process, the first mixer settler (1A) is fed by gravity at its midpoint. The feed is the aqueous stream 1AF and is taken from tank F107. A solvent stream (1AX) is metered by gravity into the organic inlet end of the mixer settler. The solvent stream (30% TBP is dodecane) is received from tank E111. The solvent flows countercurrent to the aqueous stream (1AF), and preferentially extracts uranium and thorium from fission products and other contaminants in the aqueous phase. A 0.1 $\underline{M}$ HNO_3 stream is (1AS) introduced at the aqueous inlet end of the mixer settler to back extract fission products that may have been taken up by the solvent. The 1AS stream is taken by gravity from a series of four chemical makeup tanks (E102, E104, E106, and E107). The aqueous output of mixer settler 1A is taken to waste and the organic output taken to mixer settler 1C for stripping.

The uranium- and thorium-bearing solvent stream, 1AP (0.12 $\underline{M}$ HNO_3), is received by tank E129 and fed by gravity to the mid point of the second mixer settler 1C. Here, thorium and uranium are stripped out of the organic phase, denitrated by steam stripping in feed adjustment system F402, and accumulated in tank F114. This stream, 2AF, is pumped to the midpoint of mixer settler 2A. The 2AF stream is acid-deficient and allows further decontamination of uranium and thorium from chemically similar fission products — particularly zirconium and molybdenum. A fresh solvent stream, 2AX, is introduced to one end of the mixer settler and made to flow countercurrent to the 2AS scrub stream. The 2AS scrub stream is received from tanks E108 and E842. A salting agent (13 M HNO_3), stream 2AH, is introduced between the feed point, stream 2AF, and the solvent rich end of the mixer settler. Stream 2AH is received from tank E502.

The thorium- and uranium-bearing solvent stream, 2AP, is introduced at the midpoint of mixer settler 2B for thorium partioning. Stream 2AP is received directly from mixer settler 2A. Fresh solvent, stream 2BS, is introduced to one end of the mixer settler and made to flow countercurrent to scrub stream 2BX introduced at the other end. Stream 2BS is gravity fed from tank E111. Stream 2BX is gravity fed from tank E105. The uranium-bearing organic product stream, 2BU, is passed directly to the last mixer settler 2C.

Mixer settler 2C performs as uranium stripping operation and provide aqueous uranium product at stream 2CU. Stream 2CU is stored for future work in critically safe slab tanks E140, E141, and E155. The uranium-bearing organic stream 2BU is introduced at one of the mixer settler and countercurrent flow is established by introducing scrub stream 2CX at the other end. The baren solvent stream, 2CR, is accumulated for future work by tanks E144 and E146.

7.4.2.2.2 Thorex Process - one cycle. This process is an adaptation of the two-cycle process previously described. Distinguishing differences are as follows:

> The single cycle Thorex process utilizes three mixer settlers. The cycle begins with mixer settler 2A and attempts to decontaminate a uranium- and thorium-bearing solution in one step. This is accomplished through the use of all the fission products associated with uranium and particularly thorium.
> Mixer settler 2B is used to selectively strip thorium from the solvent phase and produce it as an aqueous stream, 2BT. The uranium-bearing solvent stream, 2BU, is further processed by mixer settler 2C. In this stage, uranium is stripped from the solvent phase and produced for future work as aqueous stream 2CU.

7.4.2.2.3 Interim 23 Process (w/acid feed). This process utilizes two mixer settlers and is designed to recover and decontaminate only the uranium. Key characteristics of the interim process are described as follows:

Low (5%) TBP concentrations are used to discourage the coextraction of thorium with uranium. In this way thorium introduced in the aqueous feed remains with associated fission products while uranium is extracted to the organic phase, 1AP. This organic phase is stripped of uranium which is produced as aqueous stream 1CU.

7.4.2.2.4 Interim 23 Process (w/acid-deficient feed). This process is similar to the above described interim process but utilized acid-deficient feed for the purpose of achieving better decontamination of uranium and thorium from associated fission products.

7.4.2.2.5 Uranium Purification. This process utilizes two mixer settlers to accept a uranium feed solution and further remove any associated fission products. The first mixer settler, 1A, solvent extracts the uranium from aqueous solution and carries away decontaminants as waste. Uranium in the solvent product is back extracted into the aqueous phase and stored for future use.

7.4.2.2.6 Solvent Regeneration. Regeneration of spent solvent is also carried out in an air-pulsed mixer settler. It consists of three performance stages, each with a mixing chamber and a settling chamber (Fig. 7.7). As the scrubbing in each stage is done with a different aqueous phase, each settling chamber has its own overflow for the aqueous phase. The dimensions of the battery are 470 mm × 650 mm × 240 mm. Its capacity is 5.7 liters.

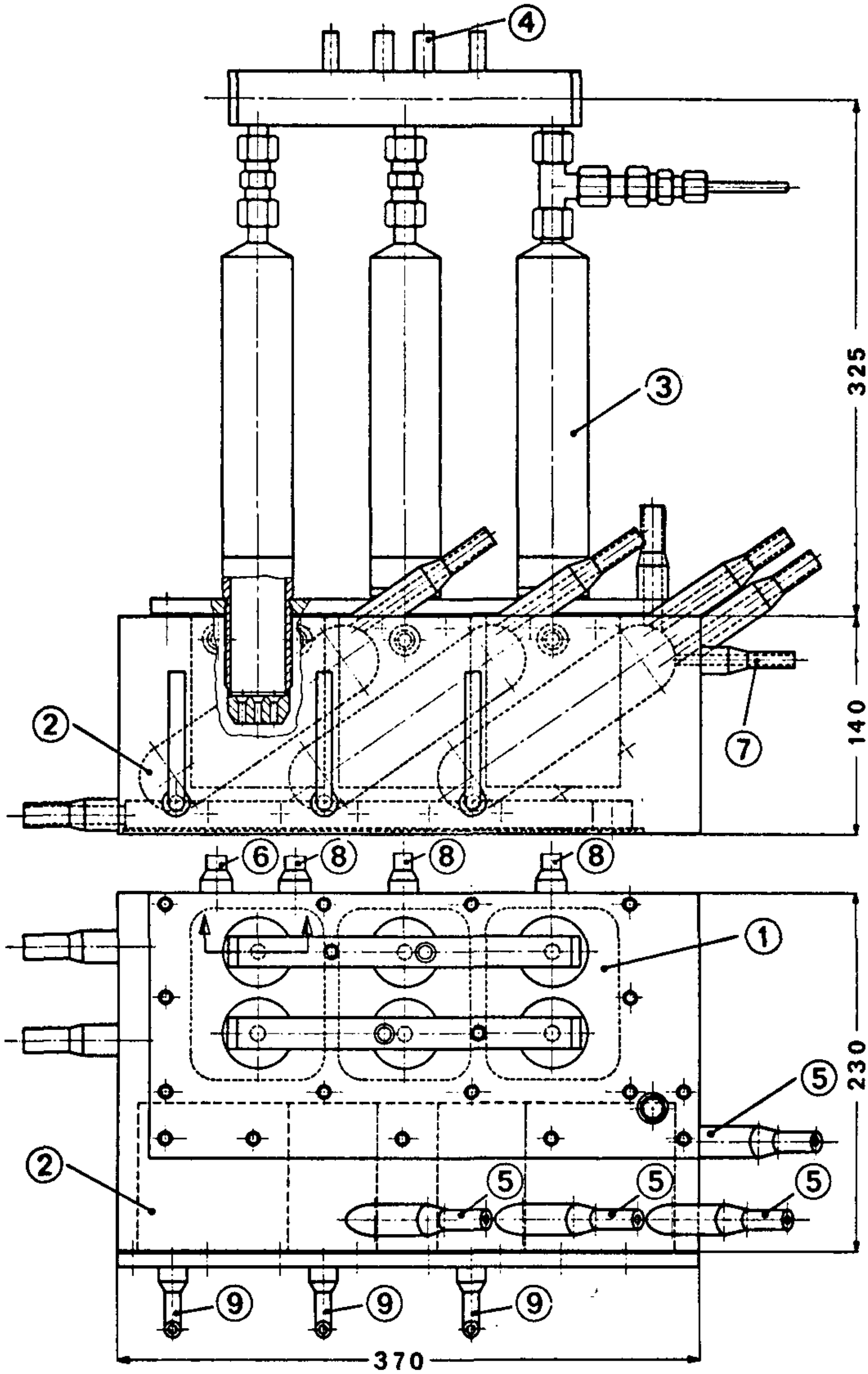


Fig. 7.7. Solvent Regenerator.

1 Mixing Chamber; 2 Settling Chamber; 3 Suction Pipe; 4 Vacuum Pipe; 5 Instrument Piping; 6 Spent Solvent Inlet; 7 Regenerated Solvent Outlet; 8 Aqueous Phase Inlet; 9 Aqueous Phase Outlet

7.4.3 Assessment

The assessment of HET and JUPITER solvent extraction systems is presented in two parts. They are Findings and Conclusions. Section 7.4.3.1 gives the assessment team's findings, elaborating on the technical issues listed in Appendix A4 and B4. Section 7.4.3.2 gives the teams conclusions concerning the scope of future cooperative work to resolve common technical issues.

7.4.3.1 Findings

Specific technical issues to be resolved by the HET and JUPITER Projects are common to both projects and are listed below:

- demonstrate acid-Thorex process,
- radiation damage effects on solvent,
- determine fission product, uranium, thorium, and plutonium retention, and
- determine influence of cruds and solids on hydrodynamics.

The specific importance of each of these issues to the HET and JUPITER Projects is discussed in Appendices A4 and B4, respectively.

7.4.3.2 Conclusions

Conclusions on each technical issue are provided below. A tabular summary of these conclusions is provided in Table 7.6.

7.4.3.2.1 Demonstrate Acid-Thorex. The operability of the solvent acid-Thorex extraction process is important to the HET and JUPITER Projects. The substitution of one project results for the other is a question of degree. The HET Project will demonstrate one cycle of the acid-Thorex process using comparatively higher burnup fuel. JUPITER Project will begin with the demonstration of two cycles of the acid-Thorex process using acid-deficient feed in the second extraction stage.

Table 7.6. Solvent Extraction Conclusion Summary

HET Technical Issues	Obtainable from JUPITER	COMMENT
1. Demonstrate acid thorex at high radiation levels	YES	• JUPITER able to run one and two cycles of acid thorex
2. Solvent radiation damage effects	YES Limited Data Available	• JUPITER system normal residence is 2–4 hrs • JUPITER regenerates mono and dibutylphosphate • JUPITER uses Na_2Co_3/NaOH washing agent and HNO_3 treatment • JUPITER fuel feed material decay time affects the degree of solvent radiation damage
3. Characterization of wastes	YES	• JUPITER to characterize waste stream with respect to the presence of Th-228, Pu, and radon in off-gas • Th can be partitioned and separated from waste stream
4. Demonstrate handling of feed solids from irradiated materials	YES	• interfacial crude and stable immulsions will form in both JUPITER and HET systems • JUPITER mixer-settler system should be more sensitive to third phase formation
5. Demonstrate ^{235}U fissile particle processing at high radiation levels	NO	• JUPITER uses single mixed (U/Th) oxide particle
6. Fission product and U/Pu/Th retention and solvent properties	YES	• JUPITER expects U and Th losses $\leqslant 1\%$

7.4.3.2.2 Radiation Damage Effects on Solvents. The HET and JUPITER Projects utilize the same solvent (30% η-tributyl phosphate TBP in kerosene) to effect the extraction and to otherwise isolate heavy metal constituents in an aqueous solution. Radiation damage to this solvent has the immediate effect of altering its selectivity or ability to preferentially extract a component(s) from aqueous solution. The secondary effect of radiation damage to the solvent is its influence on the cooling time necessary before fuel reprocessing can begin; that is, radiation tolerant solvents remove the need for long periods of fuel cooling.

JUPITER receives fuel that has a lower burnup and longer cooling time than is planned for HET solvent extraction. For this reason, JUPITER results on this technical issue are expected to improve the state-of-knowledge over cold-engineering work but not to the point expected from HET work.

7.4.3.2.3 Determine Fission Product, Uranium, Thorium, and Plutonium Retention. This common issue is concerned with the separation of desired constituents (uranium, etc.) from unwanted species (fission products). The two-cycle Thorex process to be demonstrated by JUPITER will provide more information regarding this separation than is expected from HET (one-cycle extraction). JUPITER's second cycle utilizes acid-deficients feed to effect the separation of elements that are chemically similar to thorium. Zirconium, molybdenum, and plutonium polymers are removed to aqueous waste. This additional step is not available in HET and information is desired regarding the effectiveness of acid-deficient conditions to separate constituents that are chemically similar to thorium.

7.4.3.2.4 Determine Influence of Cruds and Solids on Hydrodynamics. This technical issue speaks to the practical aspects of solvent extractio that is, the filtration or otherwise elimination of solid phase(s) from the liquid-liquid (solvent aqueous) extraction interface. The principle effect of solids at this point is negative and impairs mass transport between the liquid phases. The JUPITER information results on this issue should generally satisfy HET requirements, since the solution to the issue is largely a matter of design (pumps, filters, decanters, etc.).

7.4.3.2.5 Additional Design Issues. In discussions of the above systems and of plant design, the following additional findings became evident.

- Demonstrate the modified Purex process. Both HET and JUPITER have the capability to demonstrate this process for fissile material.
- Solvent Regeneration - the volume of radioactively contaminated solvent arising from the proposed HET/JUPITER solvent extraction systems make solvent regeneration desirable. Both projects have provisions for solvent regeneration for the purpose of minimizing waste volumes. Although the HET system utilizes a pulsed-column method and JUPITER the mixer settler method, data on this technical issue can be directly and mutually substituted.

7.5 URANIUM PRODUCT HANDLING

Appendices A5 and B5 are technical summaries of the HET and JUPITER uranium product handling systems. This section consolidates these summaries.

7.5.1 Scope of Technical Issues

The principal requirement of the HET and JUPITER uranium product handling system is to receive uranium-bearing aqueous solutions, concentrate for future use. Although these are differences between the associated HET and JUPITER designs, the scope of technical concern with these systems is as follows:

- fission product activity in condensation,
- product purity,
- product stability,
- influence of carryover solvents on evaporator performance, and
- off-gas composition.

7.5.2 Design Solutions

7.5.2.1 HET Uranium Product Handling

The HET system continuously feeds a thermosiphon evaporator with uranyl nitrate solution. The evaporator is steam heated to a 135°C operating temperature and has a boil-up rate of 73 ml/min. A shell and tube condenser (water cooled) condenses the evaporation overhead which is carried off by gravity to waste. The concentrate is made up to 1.3 M U and 0.7 M HNO_3 and then transported by gravity to a critically safe slab tank (73ρ vol).

7.5.2.2 JUPITER Uranium Product Handling

The JUPITER system for uranium product handling continuously feeds a circulation evaporator with uranyl nitrate solutions. The evaporator concentrates the solution to 175–225 g(U)/ρ and 1–3 M HNO_3. The concentrate is subsequently transferred to critically safe storage tanks. A more detailed description of the evaporator is given in Sect. 7.3.2.2, Fig. 7.3.

7.5.3 Assessment

The assessment of HET/JUPITER uranium product handling systems is presented in two parts; they are, Findings and Conclusions. Section 7.3.3.1 gives the assessment team's findings, elaborating on the technical issues listed in Appendix A5 and B5. Section 7.3.3.2 gives the team's conclusions regarding the scope of future cooperative work to resolve common technical issues.

7.5.3.1 Findings

Specific technical issues to be resolved by the HET and JUPITER Projects which are common to both projects are listed below:

- fission product activity in condensation
- uranium product purity, and
- uranium product stability.

The specific importance of each of these issues to the HET and JUPITER Projects is discussed in Appendices A and B .

7.5.3.2 Conclusions

While the Product Handling System is primarily a service facility to concentrate the uranium products prior to cell removal and site transfer, some data will be obtained. Conclusions on the important technical issue are provided below. A tabular summary of all technical issues is provided in Table 7.7.

7.5.3.2.1 Fission Product Volatility. While the fission product levels in the product are considerably lower than in feed adjustment, a measure of fission product volatility during product concentration will be attempted. This will help design the vessel off-gas system in HRDF.

7.5.3.2.2 Product Purity. The uranium product purity will be measured relative to corrosion products, fission products, thorium, and phosphorous. This data will aid in final design of HRDF uranium product system.

7.5.3.2.3 Product Stability. While no problems are expected with product stability, radiation present in these high ^{232}U bearing ^{233}U solutions will be building up as a function of storage time. This storage will be evaluated as it may effect refabrication operations.

Table 7.7. Uranium Product Handling Conclusion Summary

HET Technical Issues	Obtainable from JUPITER	Comment
1. Fission product volatility	YES	• HET and JUPITER systems concentrate uranium bearing solutions by evaporation • JUPITER to evaluate the influence of carry over solvents on evaporator performance • JUPITER to evaluate the influence of fission product volatility on off-gas composition
2. Product purity	YES	• HET uranium product specification $\leqslant$ 250 ppm ^{232}U • JUPITER uranium product specification $\leqslant$ 200 ppm ^{232}U (expected $\leq$8 ppm ^{232}U) • JUPITER to evaluate presence of thorium and fission products
3. Product stability	YES	• important to JUPITER and HET only as it affects refabrication processes • JUPITER not concerned with fabrication activities • JUPITER to evaluate product stability as it relates to safe storage

8. ADDITIONAL DESIGN ISSUES

8.1 SIZE REDUCTION: LONG-TERM PERFORMANCE OF DRY BEARINGS

The current bearings on the Pitman-Shaft of the UNIFRAME jaw crushers is a conventional oil lubricated system. Shaft seals are a recognized maintenance problem. An alternate approach would be a dry bearing (or moist air enhanced, dry bearing) with adequate cooling. Life data is required for our shaft/bearing geometry.

8.2 BURNING: ABRASION, EROSION, AND EXPANSION JOINTS

8.2.1 Abrasion Rates of Graphite and Fuel Particles on Materials of Construction at Low and Elevated Temperatures in Oxidizing and Inert Atmospheres

This data is necessary in order to establish material thicknesses and perform trade-off studies between maintainability (spaces analysis) and initial capital cost. Areas of particular interest are the crushing and screening surfaces of the fuel element crusher, curved and straight sections of pneumatic transport lines and the classifier, the particle crusher, the cyclone internal wall, the receiving surfaces of transport bunkers and rotary feeder devices.

8.2.2 Erosion — Corrosion Coupled Degradation of the Fluidized-Bed Burner Internals

The internal surfaces of the fluidized-bed burners are subject to the combined effects of erosion due to graphite/fuel particle scrubbing, high temperature oxidation in zones of high oxygen partial pressure and possible carbonization and sulphidation attack in other zones. Long-term data on these effects for Hastelloy-X and other high temperature alloys in a fluidized-bed environment are required to select economic wall thickness for the burner vessel and other internals.

8.2.3 Data on Bellows as Other Expansion Joint Performance in Particulate Environments

The configuration of head-end reprocessing equipment for gravity and pneumatic transport requires the frequent use of expansion joints (usually bellows) to absorb or compensate thermal strain thereby protecting equipment and piping. Bellows are also used to mechanically isolate hoppers on load cells for accurate weighing. A thorough study of the behavior of bellows and other style expansion joints exposed to particulates is necessary.

9. REQUIREMENT SUMMARY

The HET Project utilized a series of *requirement documents* to progressively define the project through three levels; they are, plant or project level, facility, and system. Each of the three levels of requirements have been carefully reviewed for the purpose of this assessment and selected requirements identified. The selection of specific requirements was made on the basis of applicability to the technical issues defined for each process system. Table 9.1 presents these selected requirements at all three levels, by their numeric identification in the parent document indicated. These requirements of HET are satisfied by the FRG Project JUPITER.

10. OVERALL CONCLUSIONS AND RECOMMENDATIONS

An assessment of the U.S. recycle development program's Hot Engineering Test (HET) Project and the FRG program's JUPITER Project has been completed. The assessment was directed toward the definition of a plan for technical information exchange and reduction of resource commitments otherwise needed for the respective projects.

Table 9.1. HET requirements satisfied by JUPITER Project

Level	Doc. No.	Requirement Number
0 HETF	R-002	.2, .4, .5, .6, .7, .12, .13, .16, .17, .18, .19, .19, .21, .22, .23, .24, .25, .26, .32, .33
1 HET-Repro Facility	R-005	.1.2, .2.1, .2.2, .2.3, .2.5, .2.6, .2.8, .4.1, .7.1, .8.1, .9.1, .11.3, .12.2, .12.3, .15.3, .17.1, .17.2, .18.1, .18.2, .19.1, .19.3, .21.1, .21.3, .22.1, .23.1, .23.2, .23.3, .25.1, .26.2, .27.3, .29.4, .32.1
2 Fuel Size Reduction System 1100	R-009	.2.1.1, .2.4.1, .2.7.1, .4.1.1, .4.1.2, .15.2.1, .5.2.1, .11.1.1, .11.3.1, .13.1.1, .12.2.1, .19.2.1, .21.2.1, .15.2.2, .15.3.1, .16.1.2, .16.1.3, .17.1.1, .17.1.2, .17.1.3, .17.2.1, .22.1.1, .22.1.6, .23.1.1, .23.1.3, .23.3.1, .26.1.1, .26.1.3, .26.2.1, .29.2.1, .29.2.2, .32.1.2, .32.1.3, 32.1.4
2 Primary Burning System 1200	R-009	.2.1.1, .2.1.2, .2.3.2, .5.2.1, .11.1.1, 2.7.1, .12.3.1, .19.3.1, .12.2.1, .21.1.2, .21.2.1, .15.2.1, .16.1.2, .27.2.3, .27.3.3, .27.3.6, .27.3.7, .17.1.1, .17.1.2, .18.2.1, .23.3.1, .23.1.1, .23.1.3, .26.1.1, .29.2.2, .29.4.1, .29.2.1
2 Dissolution and Feed Adjustment System 1500	R-009	.1.2.2, .1.2.3, .2.1.1, .2.6.1, .2.6.2, .8.1.1, .11.1.1, .12.1.1, .12.1.2, .12.1.3, .12.1.4, .12.1.5, .12.2.1, .12.2.2, .15.2.1, .15.3.1, .16.1.3, .16.1.4, .16.1.5, .17.1.1, .17.1.2, .17.1.3, .18.1.1, .18.1.2, .18.2.1, .18.2.2, .18.2.3, .19.2.1, .19.2.2, .22.1.1, .22.1.4, .22.1.5, .23.1.1, .23.1.2

Table 9.1. Continued

Level	Doc. No.	Requirement Number
2 Solvent Extraction System 1600	R-009	.1.2.2, .1.2.3, .2.2.1, .2.6.1, .2.7.1, .8.1.1, .12.1.1, .12.1.2, .12.1.3, .12.1.4, .12.2.2, .15.2.1, .16.1.2, .17.1.1, .18.1.1, .18.1.2, .18.2.2, .19.2.1, .19.2.2, .22.1.1, .22.1.4, .22.1.5, .23.1.1, .23.1.2
2 Product Handling System 1800	R-009	.1.2.2, .1.2.3, .2.1.1, .2.6.1, .8.1.1, .11.1.1, .12.1.1, .12.1.2, .12.1.3, .12.1.4, .12.1.5, .12.2.1, .12.2.2, .15.2.1, .15.3.1, .16.1.3, .16.1.5, .17.1.1, .18.1.1, .18.1.2, .18.2.1, .18.2.2, .18.2.3, .19.2.1, .19.2.2, .19.3.1, .22.1.1, .22.1.4, .22.1.5, .23.1.1, .23.1.2

10.1 CONCLUSIONS

The overall conclusions of this assessment are (1) that differences in HET and JUPITER facility/equipment designs do not prevent the exchange of useful technical data and (2) an efficient strategy to cooperatively develop HTGR fuel recycle technology requires maximum utilization of JUPITER data and supplemental data from U.S. hot laboratory and cold engineering scale work.

The scope of the assessment has been comprehensive in the area of reprocessing which is common to both projects. A methodical comparative system evaluation of corresponding HET and JUPITER process systems has been used to establish comparability on the basis that (1) the respective systems provide a common result; (2) consist of functional similar elements; (3) are constrained by compatible operational, developmental, and facility requirements; and (4) ultimately, whether the JUPITER systems have the ability to resolve outstanding technical issues identified for HET systems.

On the basis of findings which are summarized in Tables 7.2, 7.4, 7.5, 7.6, and 7.7, it is concluded that (1) JUPITER head-end and aqueous process systems provide experimental data that satisfy technical issues identified for Hot Enginering (HET) reprocessing, and (2) the technical compatibility of these projects allows significant substitution of JUPITER data for HET data.

It is further concluded that differences in the respective input fuels and process design preferences will require the U.S. program to supplement JUPITER data. The JUPITER flowsheet accepts BISO particle design, while the HET flowsheet accepts TRISO particle design fuels. These differences influence the distribution of fission products within the process and the number or type of equipment items required. The input fuel for HET is a TRISO-coated two-particle carbide fuel system which incorporates carbon coating as well as a particle coating layer of silicon carbide for retention of fission products; the fuel feed for JUPITER is a single-particle mixed (U/Th) oxide fuel which uses three carbon layers for retention of fission products. End products from both

HET and JUPITER include uranyl nitrate, thorium nitrate, and waste solutions. Generalized process flow diagrams describing HET and JUPITER head-end and aqueous separation processes are shown in Figs. 5.1 and 5.2, which graphically illustrate the functional similarities as well as differences of the two flowsheets.

Finally, it is concluded that the conceptual nature of HET and the physical existence of JUPITER makes cooperation both practical and cost effective. Hot engineering is an important part of engineering-scale development, and is recognized by the U.S. and FRG programs as separately identifiable projects. The U.S. program element is identified as the Hot Engineering Test (HET) Project, while the corresponding FRG program element is known by the acronym JUPITER. Both projects are designed to demonstrate HTR reprocessing in the presence of radioactivity associated with ^{232}U daughter products and fission products present in irradiated graphite reactor fuels. A comparison of the current status of the two projects supports the conclusion stated above.

The HET design work is scheduled to begin in FY 1980, ending in the third quarter of 1987. A 1 1/2 year cold checkout period is scheduled to begin the first quarter of FY 1987, followed by 2 1/2 years of hot tests. Conceptual design of the JUPITER plant was started in 1972. Construction and installation of the head-end was finished in 1978; assembly of the aqueous processing equipment is schedule to end in 1982, with cold operation of aqueous chemical processes in 1983–1984. Hot start-up of the entire plant is scheduled for 1985. Thus, common design features and a general overlap in schedules support the conclusion that cooperation between the HET and JUPITER Projects is both practical and cost effective.

10.2 RECOMMENDATIONS

The HET/JUPITER Project Assessment has sought to examine the connective relationship of the two projects at each programmatic development stage or level, and has identified the point at which the two projects converge on common objectives. Recommendations have been developed that can lead to mutually supportive roles in a cost-effective international effort to develop HTR fuel recycle technology. Overall, the assessment recommendations presented below support a cost-effective US/FRG program to jointly develop high temerature gas-cooled reactor fuel recycle technology.

The following recommendations support continued US/FRG cooperation on hot engineering tests and specifically require (1) maximum use of ongoing JUPITER plans, and (2) termination of the HET project in its present conceptual state.

AVR Carbide Fuel. JUPITER is presently designed to process AVR mixed (Th,U) oxide fuel. AVR carbide fuel is potentially available. The processing of carbide fuel would provide more exact HET-related data. Recommend JUPITER project consider this option and properly qualify this possibility.

U.S. Expand Hot-Lab Phase. A potential need exists for expanded U.S. hot laboratory work to supplement JUPITER head-end work, assure availability of aqueous separations data (JUPITER schedule 1985—1988), and to provide specific HTGR refabrication data. Recommend U.S. better define hot lab contribution to cooperative effort.

JUPITER Experimental Plan. Recommend JUPITER/HET project staff jointly prepare an experimental plan that defines data requirements, intended use, and specific plans for acquisition. Recommend HET Project Data Plan be provided JUPITER staff for the purpose of initiating discussions.

Cost/Benefit Evaluation. Recommend that the cost/benefit of US/FRG cooperation on HTR fuel recycle be verified. The evaluation should (1) include a tentative cooperative strategy plan that is based on the HET/JUPITER assessment conclusions, (2) identify which costs and which benefits are to be considered and how they are to be valued and discounted, and (3) conclude with a strategic plan of action.

ACKNOWLEDGMENT

The authors gratefully acknowledge the following U.S. and FRG colleagues for their contributions to this report.

The following individuals have contributed to the preparation of this report.

U.S.	FRG
J. Rode	R. N. Drake
L. Abraham	
J. McNair	

The following individuals have contributed material and information for use in this report.

U.S.	FRG
J. B. Strand	R. Kankura
W. S. Rickman	G. Schröder
G. E. Benedict	P. Proplesch
V. H. Pierce	
N. D. Holder	
U. S. Park	
N. W. Johanson	
R. D. Zimmerman	

APPENDIX A

HET TECHNICAL ISSUES

APPENDIX A1

SYSTEM 1100 FUEL ELEMENT SIZE REDUCTION

TECHNICAL ISSUES

1. Differences in Crushing Behavior of Irradiated and Unirradiated Fuels

The coefficients of friction and product size distribution may be different between irradiated and unirradiated fuels. These properties affect the nip angle required for crushing and the fluidization quality. Measurement of the product size distributions and determination of the maximum effective nip angle will be required for both irradiated and unirradiated fuels using the HETE fuel element size reduction system to postulate results expected in HRDF equipment.

2. Effects of Radiation on Equipment

Observation of the effects of radiation on bearings, seals, and lubricants will be required to postulate the frequency of replacement in HRDF equipment.

3. Dusting Problems

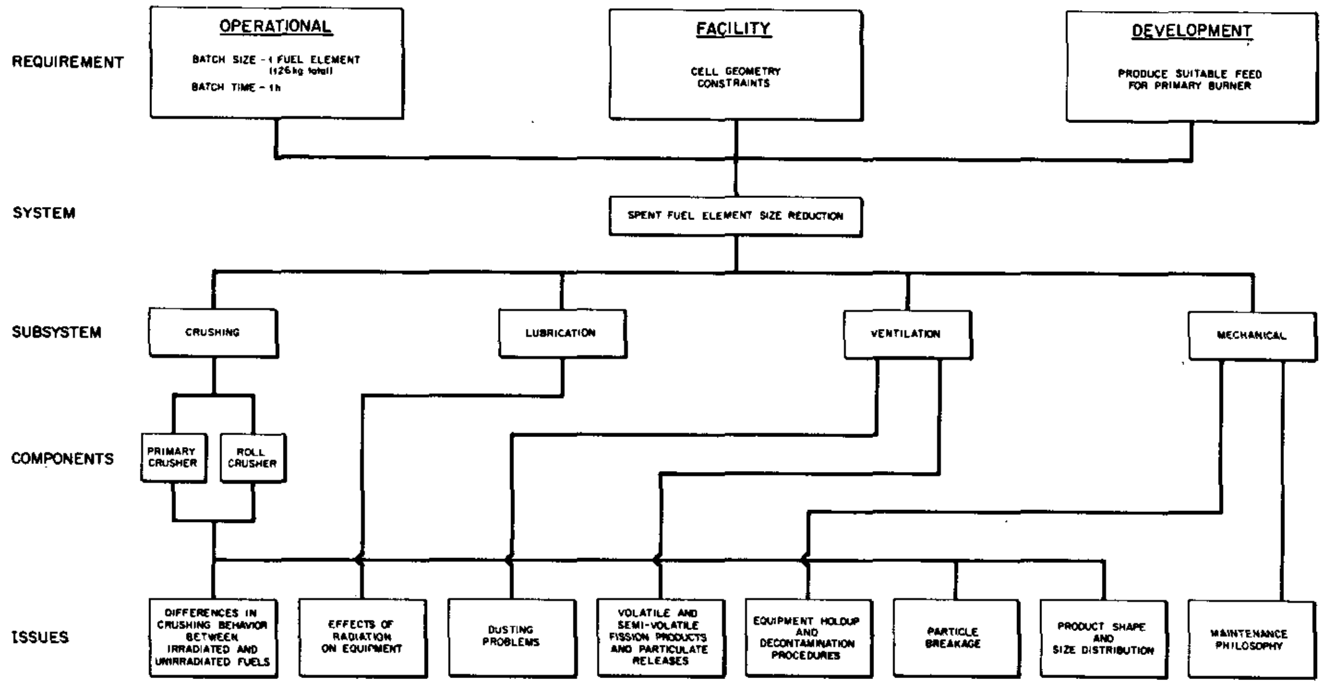
Observation of the quantity of dust generated during the crushing operations, the location of dusts, the spread of radioactivity due to dusts, and the problems associated with containment of dusts will be required to allow improvements in HRDF designs.

4. Volatile and Semivolatile Fission Products, and Particulate Releases

Determination of volatile and semivolatile fission products and particulate releases and distribution of semivolatile fission products on components of the fuel element size reduction system will be required to locate areas of high radiation and to determine off-gas treatment requirements for HRDF.

ORNL-DWG 80-9120

FUEL ELEMENT SIZE REDUCTION
TECHNICAL SUMMARY BLOCK DIAGRAM



APPENDIX A2
SYSTEM 1200 PRIMARY BURNING

TECHNICAL ISSUES

1. Material Holdup and Decontamination

Flow and fluidization properties of crushed irradiated fuel blocks may be altered from the properties of the unirradiated material that all holdup results have been based on. It is important to know that types of heel are left in the burner vessel and fines recycle system as a powder so that HRDF accountability procedures may accurately reflect actural irradiated experience.

2. Irradiated Particle Breakage*

Weakening of particle structure in irradiation may increase feed handling, fluidization, and burning particle breakage values established in unirradiated fuel studies. The result will be increased fission product release from the primary burner. The relationship of the increased breakage to the release of the fission products should be determined prior to HRDF primary burner equipment design.

3. Peak Inlet Gas O_2 and Velocity*

The possibility of changes in bed fluidization properties (see Issue 1 above) and increased bed heat content (see Issue 9) may alter the composition and velocity of the fluidization gas from the ranges recommended by unirradiated fuel burning tests. These parameters are

---

*Issues 2, 3, 4, 5, and 6 are interrelated, i.e., 2. Irradiated Particle Breakage affects 4. Buildup of Oxide, Hulls, and Fission Products in the Fines System, while 3. Peak Inlet Gas O_2 and Total Velocity would affect 2. Irraidated Particle Breakage and also 6. Particle Agglomeration Due to Fission Products. These interrelationships should be considered in experimental planning and in interpretation of HET results for HRDF Design.

fundamental and affect not only release of fission products but operating technique, campaign duration, burner component design, etc.

4. Buildup of Oxides, Hulls, and Fission Products in the Fines System*

The fines system may act as a concentrator of heavy metal oxides due to particle breakage. Also, the large surface area of the recycling fines may trap fission products especially if significant fines cooling occurs in the recycle loop upstream of (or in) the cyclone. The effects of the increasing concentrations of oxides, hulls, and fission products should be known. Capability to sample the fines during a campaign and even withdraw a mass of fine material high in noncombustible concentration should be determined.

5. Distribution of Fission Product Plateout*

Distribution of semivolatile fission products in the sintered Hastelloy Z off-gas filters should be determined as a function of operating time. Projections will then be allowed as to maximum number of burner runs allowed in HRDF before filter replacement is required. This would be due to either plugging of the pores with a gross quantity of condensed fission products, or due to excessive in-situ decay heating leading to structural failure. Plateout in the fines recycle system lines, valves, and hopper should also be monitored upon scheduled disassembly. A removable section of pipe below the fines hopper valve may be analyzed periodically for buildup.

6. Particle Agglomeration Due to Fission Products*

The release of certain species from irradiated broken particles may enhance particle agglomeration due to formation of eutectic compounds.

---

*Issues 2, 3, 4, 5, and 6 are interrelated, i.e., 2. Irradiated Particle Breakage affects 4. Buildup of Oxide, Hulls, and Fission Products in the Fines System, while 3. Peak Inlet Gas O_2 and Total Velocity would affect 2. Irraidated Particle Breakage and also 6. Particle Agglomeration Due to Fission Products. These interrelationships should be considered in experimental planning and in interpretation of HET results for HRDF Design.

The product analyses may determine the quantity and size of these agglomerates and indicate changes in fluidization, gas, and velocity of O_2 content necessary to reduce agglomeration.

7. Fission Product Corrosion and Migration Into Hastelloy X

Fission product migration and subsequent corrosion effects in Hastelloy X at elevated temperatures is an unknown at present with important implications for HRDF vessel design life studies. This may be determined at the close of HET work.

8. Cooling Needed Due to Fission Product Decay Heat

Decay heat of accumulated fission products (either plated on the wall or as dust on the surface) may have to be dealt with during between run periods. Cooling from either internal CO_2 flow and/or external shroud cooling air may be required. This may increase as more burner runs are made and must be determined empirically to allow the provisions to be made in the HRDF design.

9. Heating Reduced Due to Fission Product Decay Heat

Fission product decay heat in the incoming crushed fuel may serve to shorten burner heatup time to ignition. This can be modeled prior to operation. Empirical data gathered would then serve to verify and modify the model to allow HRDF burner cycle times to be more accurately calculated. Tail-burning heating power may also be reduced by the increased heat content (decay heat) of the final product bed.

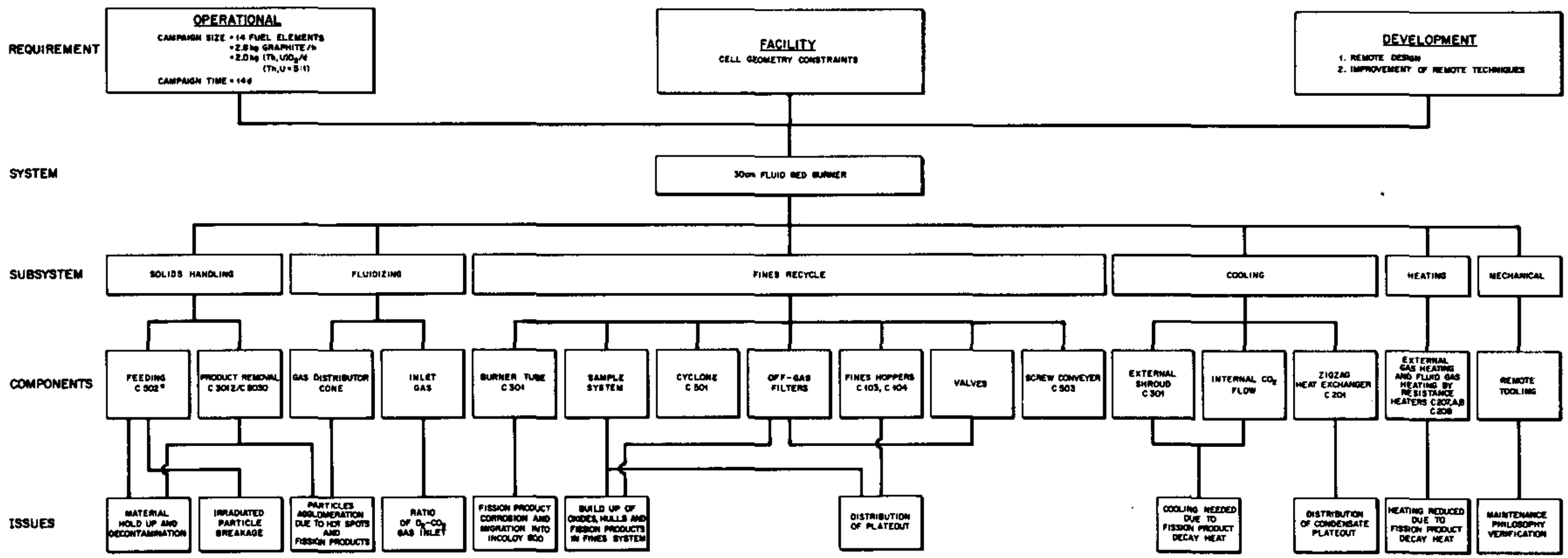
10. Maintenance Philosophy Verification

A straightforward maintenance philosophy has been used for HET conceptual design. It will form the basis of HRDF maintenance philosophies but only after successful demonstrated use in the HETF. The operations will be done as normal maintenance during HET campaigns.

ORNL-DWG 80-9116

BURNING

TECHNICAL SUMMARY BLOCK DIAGRAM



* NUMBERS CORRESPOND TO THOSE OF THE FLOWSHEET OF THE JUPITER SAFETY REPORT.

APPENDIX A3
SYSTEM 1500 DISSOLUTION AND FEED ADJUSTMENT

TECHNICAL ISSUES

1. Dissolution Rate as a Function of Irradiation History

The dissolution rate of the burner ash will be determined to measure unanticipated changes in dissolution as a function of irradiation history. It is important to know whether dissolution rates are markedly changed from unirradiated fuel in order to design an adequate dissolver system for HRDF.

2. Fission Product, Boron and Fluoride Volatility and Iodine Retention

The behavior of iodine and fission products in dissolution and feed adjustment must be known in order to design the off-gas system for HRDF. Boron and fluoride volatility in the presence of fission products is not anticipated to be different than in the cold pilot plant, but confirmation is needed. The boron and fluoride can lower the quality and restrict uses of recovered acid.

3. Demonstrate Effectiveness of Hull Separation and Washing

The SiC hulls and insoluble fission products must be removed from the dissolver and separated from the dissolver solution with effective washing. While these steps will be adequately tested in the cold pilot plant, confirmation of separation and washing steps is needed with fully irradiated feed materials.

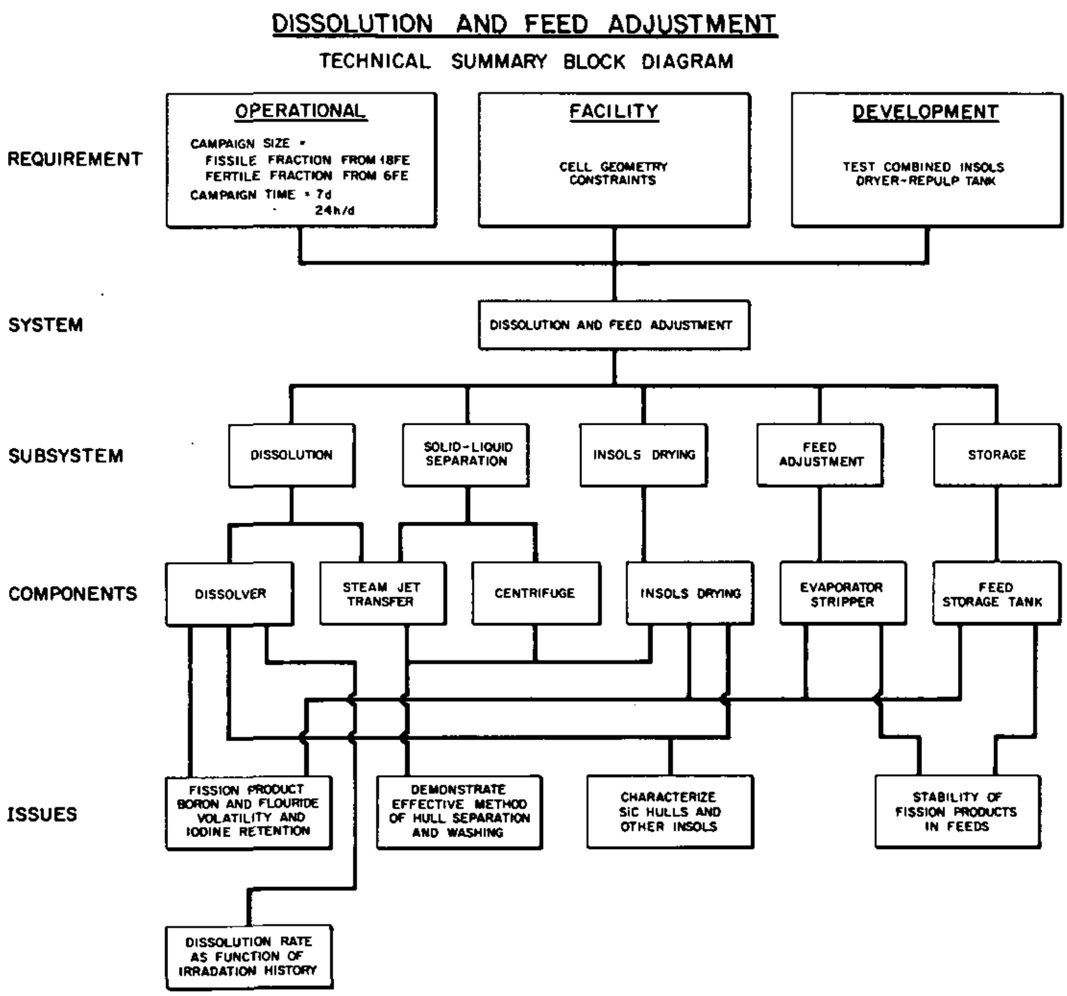
4. Characterize SiC Hulls and Other Insols

The SiC hulls will retain some fission products, and finely divided insoluble fission products will also be separated from the dissolver solution along with the hulls. Characterization of these materials is needed in order to evaluate disposal methods.

5. Stability of Fission Products in Feed

High concentrations of fission products in solution are known to post precipitate on standing. Knowledge of fission product precipitation through feed adjustment and feed storage is required to evaluate whether additional feed clarification is needed.

ORNL-DWG 80-9122



APPENDIX A4
SYSTEM 1600 SOLVENT EXTRACTION

TECHNICAL ISSUES

1. Demonstration of Acid Thorex at High Radiation Levels

The acid thorex process has been used on a production scale at moderate radiation levels. Changes have been made in the flowsheet based on GA Cold Pilot Plant solvent radiation damage tests. Verification of the expected improvements is needed to increase the HRDF operating time between column cleanouts.

2. Solvent Radiation Damage Effects

Even with modern straight chain hydrocarbon diluents, some damage to the solvent occurs. Changes in column operation will be studied as a function of solvent use time in radioactive service.

3. Characterization of Wastes

The solvent extraction waste solution will be studied to evaluate solids separation and fission product post precipitation after the thorium and uranium are removed. These data are needed to evaluate fission product buildup and heat loads in HRDF waste vessels. At system shutdown, the last batch of aqueous waste could be concentrated using the product concentrator to evaluate its effect on fission products.

4. Demonstration of Handling Actual Feed Solids from Irradiated Materials

Feed solids passing the cold pilot plant centrifuge have been evaluated in solvent extraction. Verification is needed that the solids from irradiated feed materials will also pass through the extraction column to the aqueous waste.

5. Demonstration of ^{235}U Fissile Particle Processing at High Radiation Levels

While no irradiated fuel blocks are available during the present scope of HET, "reference fuel fissile particles" should be tested through dissolution and solvent extraction. At the present time, future HTGR fuels are unknown and this requirements may be removed prior to HET final design.

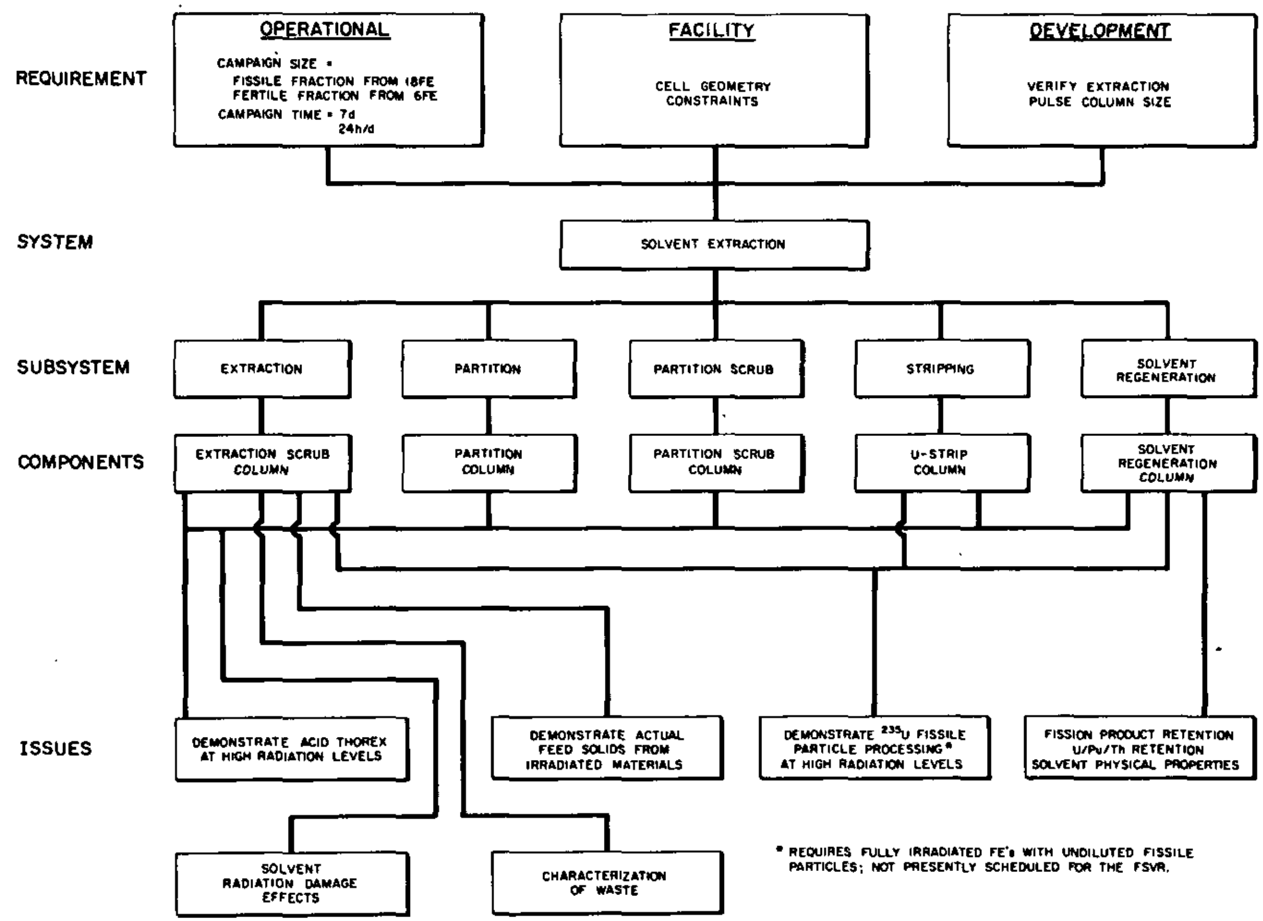
6. Solvent Fission Product and U/Pu/Th Retention and Solvent Physical Properties

The quality of the washed HET solvent will be measured as a function of irradiation history around these parameters. Solvent quality is important in long-term processing of irradiated materials, and a short-term demonstration in HET will increase confidence in HRDF long-term solvent extraction operation.

ORNL-DWG 80-9123

SOLVENT EXTRACTION

TECHNICAL SUMMARY BLOCK DIAGRAM



* REQUIRES FULLY IRRADIATED FE's WITH UNDILUTED FISSILE PARTICLES; NOT PRESENTLY SCHEDULED FOR THE FSVR.

APPENDIX A5
SYSTEM 1800 PRODUCT HANDLING

TECHNICAL ISSUES

While the Product Handling System is primarily a service facility to concentrate the uranium products prior to cell removal and site transfer, some data will be obtained.

1. Fission Product Volatility

While the fission product levels in the product are considerably lower than in feed adjustment, a measure of fission product volatility during product concentration will be attempted. This will help design the vessel off-gas system in HRDF.

2. Product Purity

The uranium product purity will be measured relative to corrosion products, fission products, thorium, and phosphorous. These data will aid in final design of HRDF uranium product system.

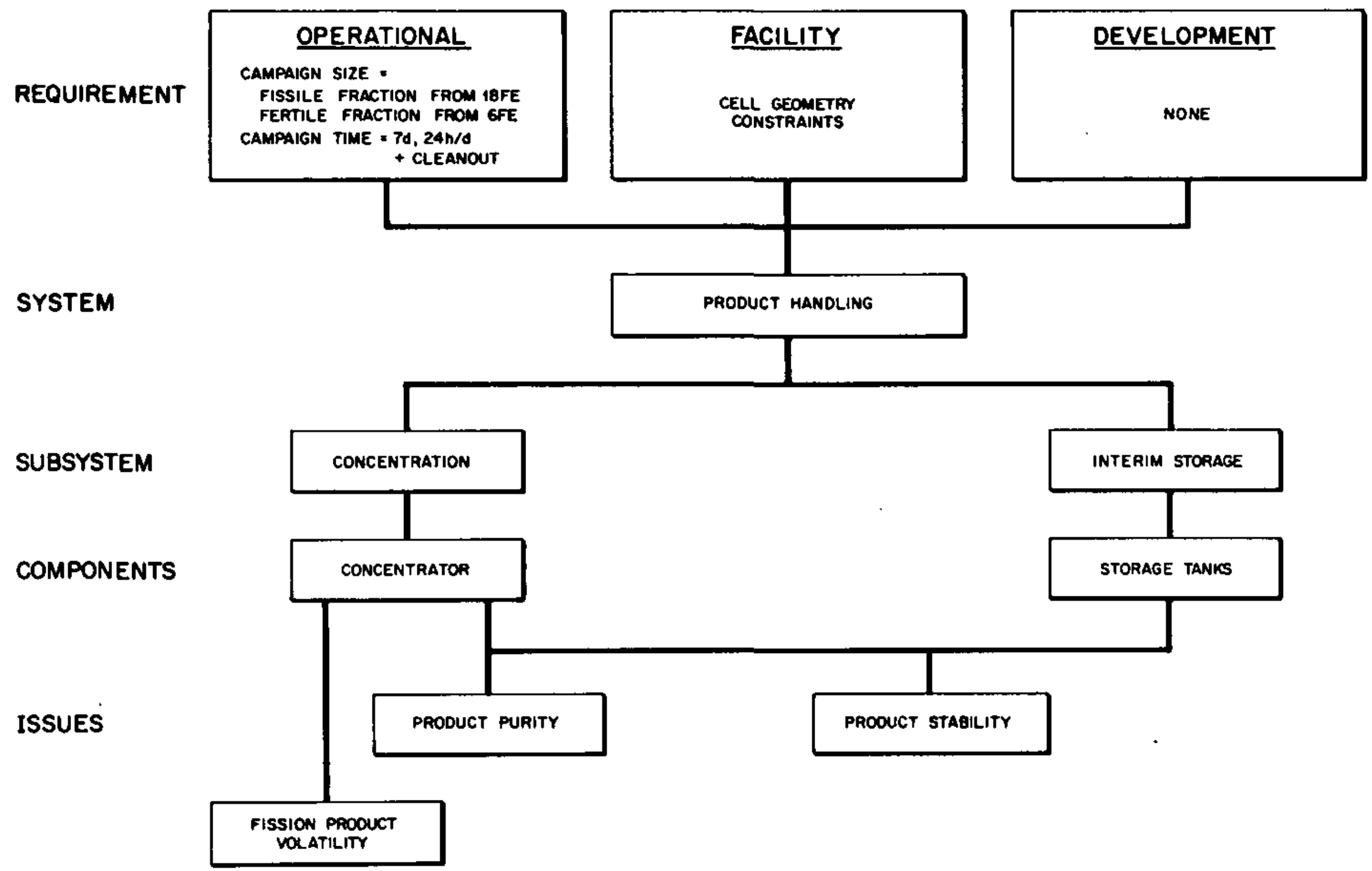
3. Product Stability

While no problems are expected with product stability, radiation present in these high ^{232}U bearing ^{233}U solutions will be building up as a function of storage time. This storage will be evaluated as it may effect refabrication operations.

ORNL-DWG 80-9124

PRODUCT HANDLING

TECHNICAL SUMMARY BLOCK DIAGRAM



APPENDIX B

JUPITER TECHNICAL ISSUES

APPENDIX B1
SYSTEM: BRENNELEMENT - ZERKLEINERUNG

TECHNISCHE PROBLEMSTELLUNGEN

1. Hammermühle

   - Unterschiedliches Mahlverhalten zwischen bestrahlten und unbestrahlten Brennelementen
   - Partikelbruchrate
   - Korngrößenverteilung

2. Bunker

   Mögliche Zeitverfestigung des Mahlgutes: Unterschiede zwischen bestrahltem und unbestrahltem Material.

3. Brennelement - Zuführung

   Unterschiede im Reibungsbeiwert zwischen bestrahlten und unbestrahlten Brennelementen.

4. Dosierschnecke

   Partikelbruch: Unterschiede zwischen bestrahlten und unbestrahlten Brennelementen.

5. Dichtungen, Kompensator

   Unterschiede im Materialverhalten zwischen bestrahlten und unbestrahlten Brennelementen.

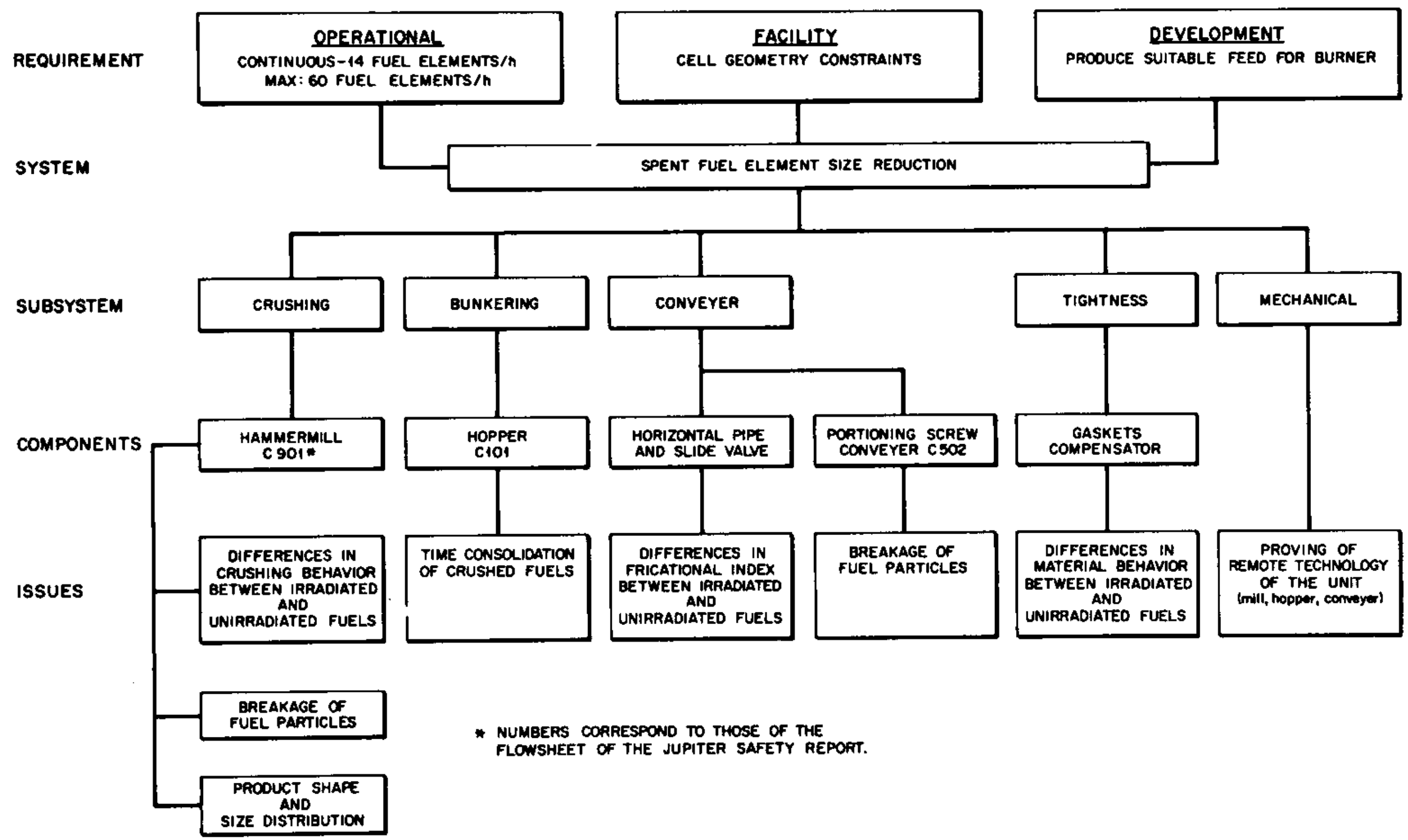
6. Nachprufüng der Manipulierbarkeit der Einheit Mühle, Bunker, Dosierschnecke

   Die Einheit ist für Fernbedienbarkeit konstruiert.

ORNL-DWG 80-9115

FUEL ELEMENT SIZE REDUCTION

TECHNICAL SUMMARY BLOCK DIAGRAM



APPENDIX B2

SYSTEM: VERBRENNUNG

TECHNISCHE PROBLEMSTELLUNGEN

1. Material - Rest und Dekontamination

Zwischen bestrahlten und unbestrahlten Partikeln und gemahlenem Graphit ist ein unterschiedliches Fließverhalten möglich. Beim Ausschleusen von Schwermetall können Äunderungen bezgl. Bestrahlten un unbestrahlten Partikeln auftreten. (Siehe auch 3.)

2. Bruch Bestrahlter Partikel

Unter Bestrahlung kann sich die Struktur der Partikel soweit ändern, daß diese beim Wirbeln und Abbrennen eine höhere Bruchrate aufweisen als unbestrahlte Partikel.

3. Partikel - Sinterung aufgrund von örtlichen Überhitzungen und Spaltprodukten

Bestrahlte und unbestrahlte Partikel können unterschiedliches Verhalten bei kurzzeitigen Hot Spots zeigen. Zusätzlich könnten Spaltprodukte zum Sintern beitragen.

4. Verhältnis des O_2 - CO_2 - Stromes

Bei möglichem unterschiedlichen Verhalten von Verbrennungsgut in der Wirbelschicht kann ein anderes Strömungsverhältnis von O_2 zu CO_2 nötig werden. Davon kann wegen anderer Strömungsverhältnisse der Feingutaustrag beeinflußt werden.

5. Korrosion durch Spaltprodukte und deren Eindringung in den Werkstoff Incoloy 800

Die Auswirkungen von Ablagerungen von Spaltprodukten im Bereich des Anströmbodens sind zu untersuchen.

6. Ablagerungen von Oxiden, Schalen und Spaltprodukten im Feistaub-System

Im Feinstaubsystem wird sich bei längerem Anlagenbetrieb ein unverbrennbarer Feinstaubanteil ansammeln. Auswirkungen auf den Gesamtbetrieb sind zu untersuchen.

7. Verteilung von Ablagerungen

Im Zickzack-Wärmetauscher und den nachfolgenden Systemen wie Zyklon, Abgasfilter, Rohrleitungen, Ventilen, können sich kondensierte Spaltprodukte ablagern. Entlang der Kühlstrecke des Zickzack-Wärmetauschers können die Kondensate der unterschiedlichen Spaltprodukte gemessen werden.

8. Kuhlung wegen der Abwärme der Spaltprodukte

Kondensierte Spaltprodukte im Kühler können zu einer Verschlechterung der Kühlleistung führen. Zusätzlich muß wegen dieser Spaltprodukte mehr Wärme abgeführt werden.

9. Verkürzung der Aufheizzeit

Durch die Abwärme des Schwermetalls (ca. 200–400 watt) läßt sich möglicherweise die Aufheizzeit reduzieren.

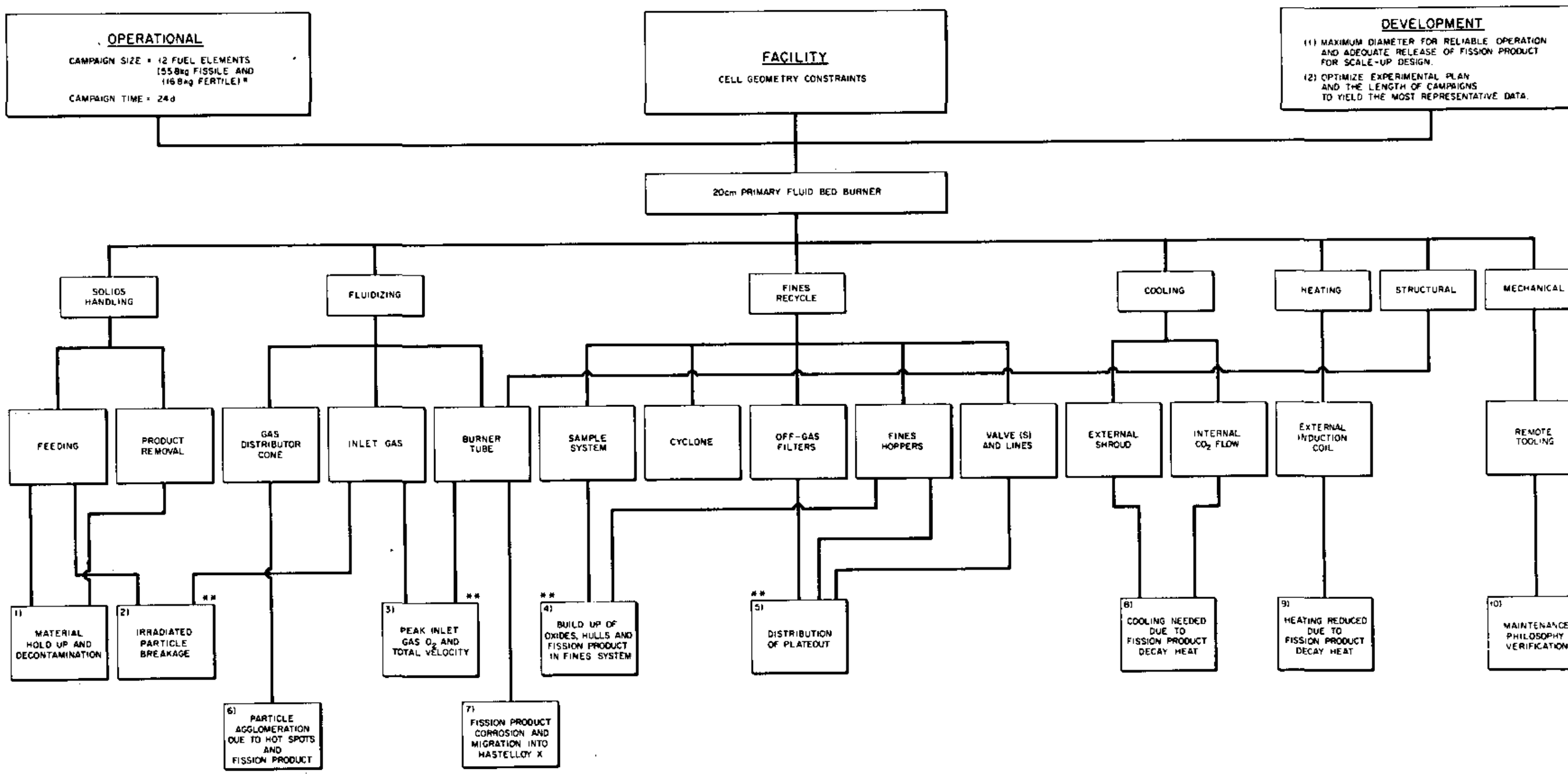
10. Manipulierbarkeit

Sämtliche Anlagenteile in der Zelle sind im Hinblich auf Manipulierbarkeit konstruiert, um eine fernbediente Wartung zu ermöglichen.

ORNL-DWG 80-9121

PRIMARY BURNING

TECHNICAL SUMMARY BLOCK DIAGRAM



* LHTGR BLOCK LOADING BASIS
** INTERRELATED ISSUES

APPENDIX B3

SYSTEM: AUFLÖSUNG UND SPEISE LÖSUNGSEINSTELLUNG

TECHNISCHE PROBLEMSTELLUNGEN

1. Auflösegeschwindigkeit des Brennstoffes und Gehalt an Unloslichen Bestandteilen als Funktion des Abbrandes

In der JUPITER-Anlage wird zum Auflösen des Brennstoffes ein kontinuierliches Verfahren angewandt. Zur Festlegung der Betriebsparameter des kontinuierlichen Auflösers sind die Auflösegeschwindigkeit sowie die Menge an unlöslichen Bestandteilen als Funktion des Abbrandes zu bestimmen. Aufgrund früherer Ergebnisse ist davon auszugehen, daß die Auflösegeschwindigkeit von abgebranntem Material größer ist als von unbestrahltem Brennstoff. Genaue Daten müssen jedoh noch ermittelt werden.

2. Chemische Zusammensetzung und Spaltstoffgehalt der Unlöslichen Rückstände

Über die Natur der beim Auflösen abgebrannter HTR-Brennstoffe verbleibenden unlöslichen Rückstände liegen bisher nur wenige Daten vor. Die chemische Zusammensetzung der Rückstände ist zu bestimmen; ebenso der Gehalt an Spaltstoff.

3. Verflüchtigung von Spaltprodukten und Fluorid

Um Basisdaten für die Auslegung von Abgasreinigungssystemen zu erhalten, ist das Verhalten der Spaltprodukte beim Auflösen des Brennstoffes und bei der Einstellung der Speiselösung zu untersuchen. Neben den echt gasförmigen Spaltprodukten wie Krypton interessiert insbesondere Jod. Außerdem ist der bei der Wasserdampfdestillation übergebende Anteil an Fluorid quantitativ zu bestimmen, um Aussagen über die Qualität der bei der Säurerückgewinnung anfallenden Salpetersäure machen zu können.

4. Schaumbildung bei der Speiselösungseinstellung

Es ist zu untersuchen, ob in Anwesenheit von Spaltprodukten bei der Einstellung von Speiselösungen eine Schaumbildung auftritt und wie ggf. Dieser den Prozeßablauf störende Effekt unterbunden werden kann.

5. Klärung von Speiselösungen

Um Betriebsstörungen als Folge von Verstopfungen in Rohrleitungssystemen, Ventilen, Förderorganen, Mischabsetzern etc. zu verhindern, müssen Speiselösungen von Feststoffanteilen befreit werden. In der JUPITER-Anlage werden hierfür Filter eingesetzt. Die optimale Porengröße ist zu bestimmen sowie ein geeignetes Filtermaterial zu ermitteln.

6. Verhalten der Spaltprodukte in Speiselösungen

Es ist bekannt, daß in Speiselösungen mit hohen Spaltproduktkonzentrationen während der Lagerung Ausfällungen auftreten können. Um Aussagen über die Zahl der notwendigen Filterationsschritte machen zu können, werden Kenntnisse über das Langzeitverhalten dieser Lösungen benötigt.

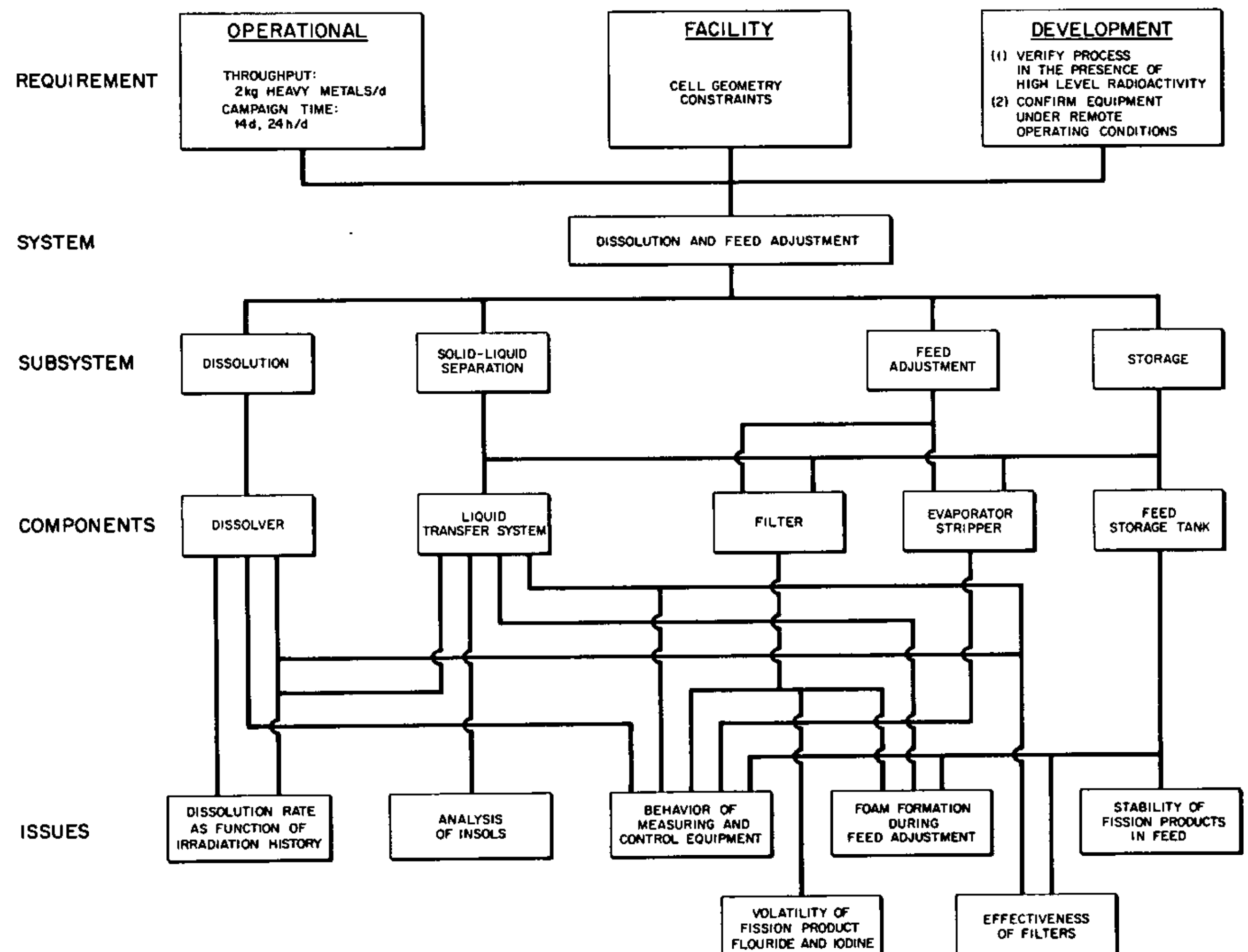
7. Betriebsverhalten vom Komponenten der Meß-, Steuer- und Regelungstechnik

Über den Einfluß stark ionisierender Strahlen auf spezielle Armaturen, Meß-geräten sowie Füllstands- und Leitfähigkeitssonden liegen bisher nur wenige Daten vor. Weitere Betriebserfahrungen hierüber sind für die Konzipierung technischer Anlagen erforderlich.

ORNL-DWG 80-9118

DISSOLUTION AND FEED ADJUSTMENT

TECHNICAL SUMMARY BLOCK DIAGRAM



APPENDIX B4
SYSTEM: SOLVENT-EXTRAKTION

TECHNISCHE PROBLEMSTELLUNGEN

1. Demonstration der Anwendbarkeit des ein- und Zweizyklischen Thoresprozesses, Sowie der Interim-Prozesse Mit Saurer und Säureunterschüssiger Speiselösung auf Thorium-Uran-Mischoxidbrennstoffe

Die extraktive Rückgewinnung von Thorium und/oder der Uran aus Lösungen hochabgebrannter Thorium-Uran-Mischoxidbrennstoffe ist im Pilotmaßstab zu demonstrieren. Um die Festlegng eines Referenzfließbildes für eine technische Anlage zu ermöglichen, sind für die einzelnen Fließschematas folgende Daten unter Betriebsbedingungen zu ermitteln:

- Wertstoffausbeute
- Güte der Thorium/Uran-Trennung
- Dekontaminationsfaktoren
- Pu-Verteilung

2. Nachweis der Brauchbarkeit Luftgepulster Mischabsetzer bei der Wiederaufarbeitung Bestrahlter Brennelemente

Luftgepulste Mischabsetzer sind wegen des Fehlens mechanisch bewegter Teile für einen Einsatz in Heißen Zellen besonders gut geeignet. Um ihre Brauchbarkeit für die Wiederaufarbeitung hochabgebrannter Brennelemente zu belegen, ist der Einfluß von evtl. auftretenden Fällungen, pastösen Verunreiningungen sowie von Schichtungen wasseriger Phasen unterschiedlicher Dichte auf die Verfugbarkeit zu untersuchen.

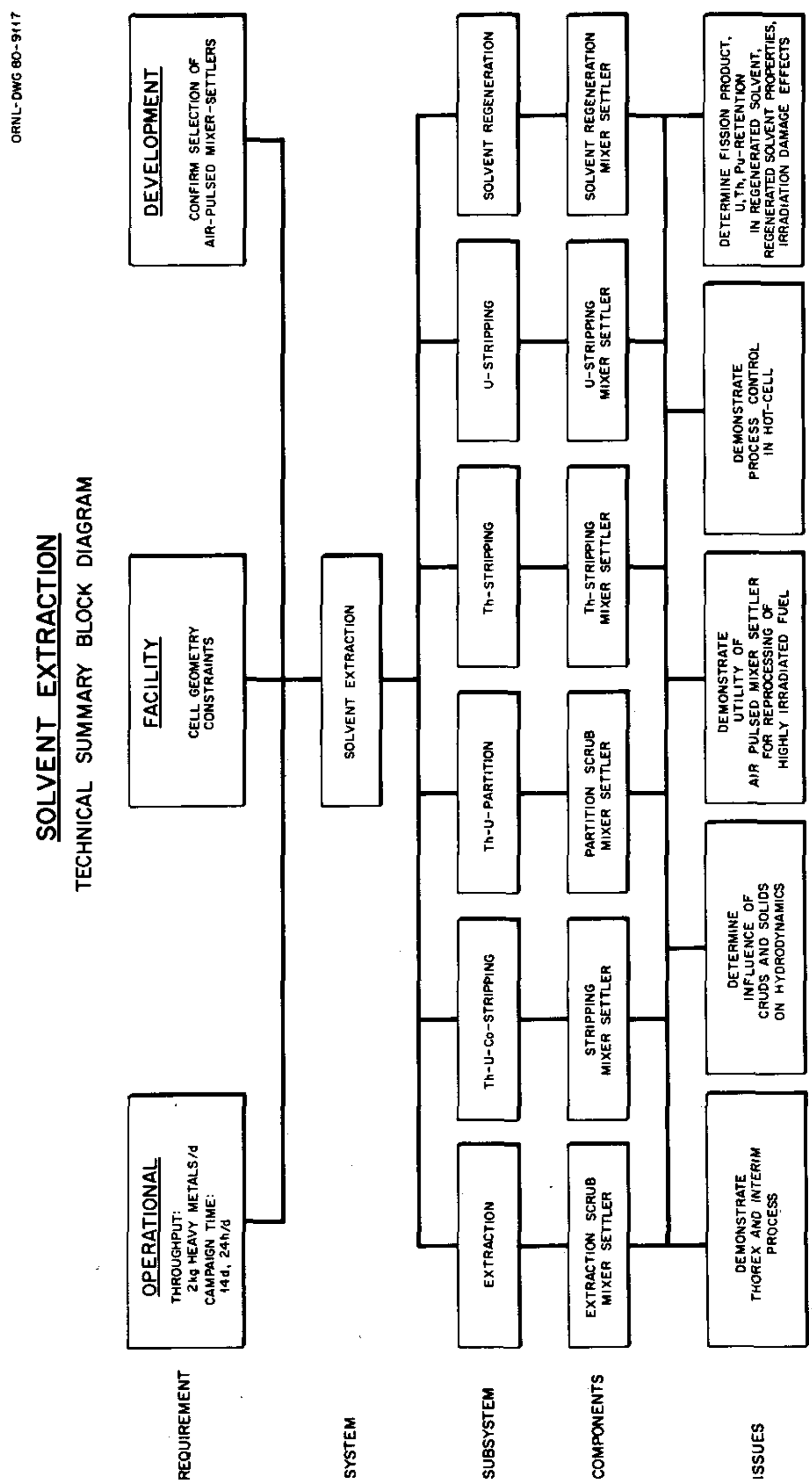
3. Strahlenzersetzung des Solvents

Infolge chemischer Reaktoinen und aufgrund der Strahlendegradation wird sich die Qualität des Solvents ändern. Die Auswirkung der Strahlenbelastung muß im Hinblick auf die Ermittlung etwaiger Grenzen der Verwendbarkeit des Solvents untersucht werden. Innerhalb dieser

Grenzen ist der notwendige Reinigungsaufwand für eine Rezyklierung zu untersuchen. Das gereinigte Solvent zeigt möglicherweise ein anderes Extraktionsverhalten als frisch eingesetztes. Je nach Notwendigkeit sind daher physikalische und chemische Eigenschaften des gereinigten Solvents sowie dessen Restbeladungen mit FP, Pu, Th, U zu bestimmen.

4. Verflgung von festen Bestandteilen der Brennstoffpartikel und des Brennelement-Graphits

Wegen der Verwendung von Filtern an Stelle einer Zentrifuge ist in der JUPITER-Anlage nicht mit einer Verschleppung von festen Bestandteilen aus dem Auflöser in die Extraktionsapparate zu rechnen. Aus Gründen der Betriebssicherheit bedarf dieser Punkt jedoch einer ständigen Überprüfung.


ORNL-DWG 80-9117
SOLVENT EXTRACTION
TECHNICAL SUMMARY BLOCK DIAGRAM
REQUIREMENT
SYSTEM
SUBSYSTEM
COMPONENTS
ISSUES
OPERATIONAL
THROUGHPUT: 2kg HEAVY METALS/d
CAMPAIGN TIME: 14d, 24h/d
FACILITY
CELL GEOMETRY CONSTRAINTS
DEVELOPMENT
CONFIRM SELECTION OF AIR-PULSED MIXER-SETTLERS
SOLVENT EXTRACTION
EXTRACTION
Th-U-Co-STRIPPING
Th-U-PARTITION
Th-STRIPPING
U-STRIPPING
SOLVENT REGENERATION
EXTRACTION SCRUB MIXER SETTLER
STRIPPING MIXER SETTLER
PARTITION SCRUB MIXER SETTLER
Th-STRIPPING MIXER SETTLER
U-STRIPPING MIXER SETTLER
SOLVENT REGENERATION MIXER SETTLER
DEMONSTRATE THOREX AND INTERIM PROCESS
DETERMINE INFLUENCE OF CRUDS AND SOLIDS ON HYDRODYNAMICS
DEMONSTRATE UTILITY OF AIR PULSED MIXER SETTLER FOR REPROCESSING OF HIGHLY IRRADIATED FUEL
DEMONSTRATE PROCESS CONTROL IN HOT-CELL
DETERMINE FISSION PRODUCT, U, Th, Pu-RETENTION IN REGENERATED SOLVENT, REGENERATED SOLVENT PROPERTIES, IRRADIATION DAMAGE EFFECTS

APPENDIX B5

SYSTEM: HANDHABUNG DER URAN-PRODUKTLÖSUNG

TECHNISCHE PROBLEMSTELLUNGEN

Die aus den verschiedenen Prozessen resultierenden Uranproduktlösungen werden in einem Verdampfer bis zu einem Urangehalt von 175 - 225 g/l und einer Salpetersäurekonzentration von 1–3 M aufkonzentriert. Nach Zwischenlagerung in einem geometrischen kritisch sicheren Behälter erfolgt der Abtransport in das außerhalb der JUPITER-Anlage gelegene Uranylnitratlager.

Folgende Daten sind im Hinblick auf eine Auslegung technischer Systeme und zur Festlegung von Spezifikationen für das Endprodukt zu bestimmen.

1. Aufkonzentrierung

(a) Einfluß von evtl. vorhandene TBP/Dodecan-Resten auf das Verdampfungsverhalten (Schaumbildung) und die Produktqualität (ölige Verunreinigungen).

(b) Aktivität des Kondensates.

(c) Aktivität des aufkonzentrierten Produktes.

(d) Chemische Zusammensetzung des aufkonzentrierten Produktes
- Uran- und Säuregehalt
- Thorium-Gehalt
- Gehalt an Verunreinigungen (Korrosionsprodukte und Phosphor)
- Gehalt an Spaltprodukten
- Gehalt an Transuranen (Np, Pu, Am)

2. Lagerung

(a) Rn, H_2 and O_2 - Gehalt des Abgases

(b) Behälterkorrosion

(c) Produktstabilität

ORNL-DWG 80-9119

URANIUM-PRODUCT HANDLING

TECHNICAL SUMMARY BLOCK DIAGRAM